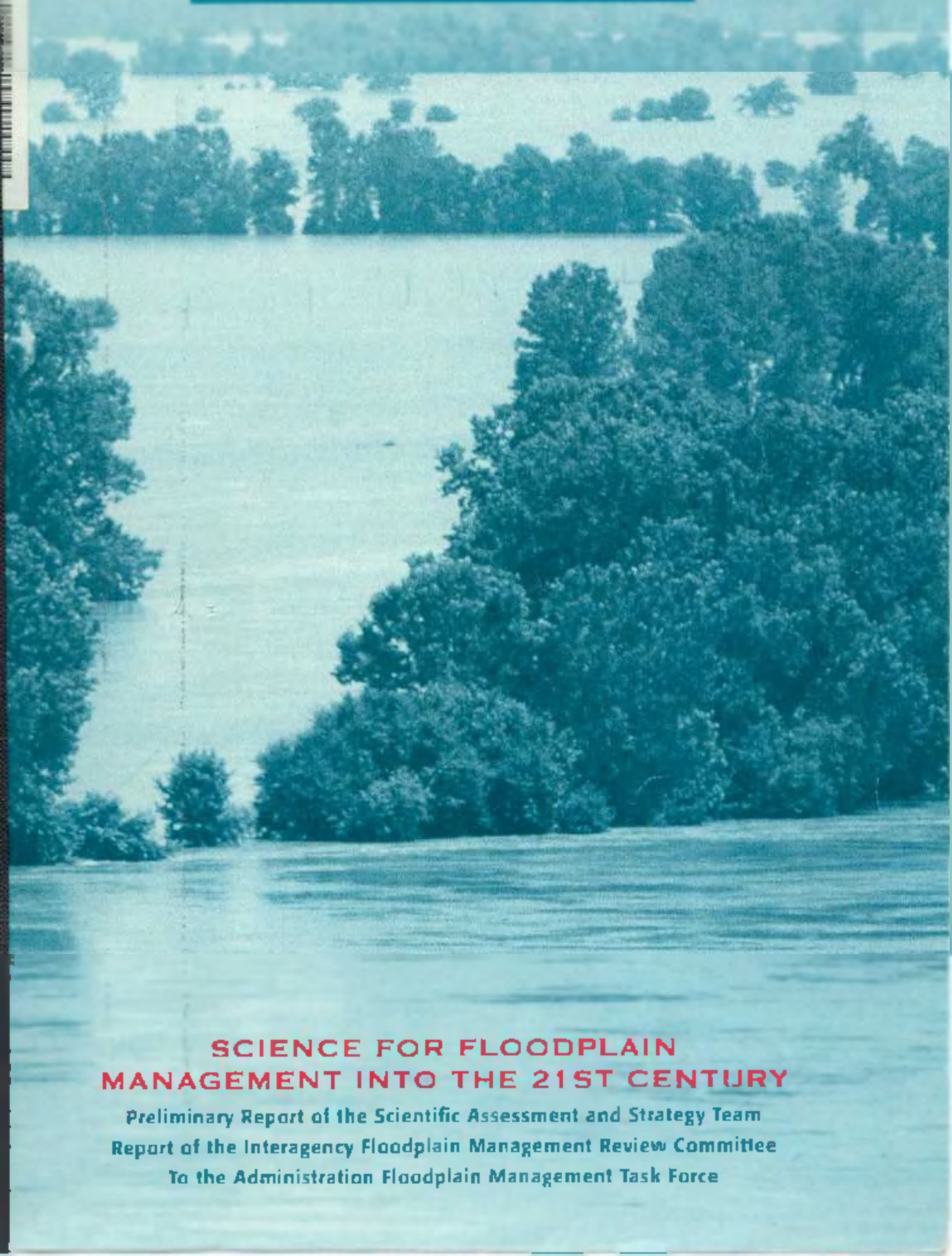
A BLUEPRINT FOR CHANGE
PART V



SCIENCE FOR FLOODPLAIN MANAGEMENT INTO THE 21ST CENTURY

Preliminary Report of the Scientific Assessment and Strategy Team

Report of the Interagency Floodplain Management Review Committee

To the Administration Floodplain Management Task Force

Vol 1 SAST

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Administration Floodplain Management Task Force

WASHINGTON, D.C.
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SAST

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CONTENTS

Section III: THE NATURAL SYSTEM

Chapter 3 HYDROLOGY

Chapter 4 PHYSIOGRAPHY

Chapter 11: STRATEGY

Section VI: APPENDICES

List of Tables

List of Figures

Section I

INTRODUCTION

The Scientific Assessment and Strategy Team (SAST) was established by a directive of the White House on November 24, 1993, to provide scientific advice and assistance to officials responsible for making decisions with respect to flood recovery in the Upper Mississippi River Basin. The Interagency Floodplain Management Review Committee (FMRC) formed on January 10, 1994. The SAST joined it then and had responsibilities to the FMRC as well as responsibilities independent of the FMRC to obtain, organize, analyze, and distribute scientific data and information. Part of that advice and assistance is included in this report. An assessment is made of selected sub-systems within the river basin providing information on how they contribute to flooding, how they respond to flooding, and how they have been affected by changes in flood pulse.

Section I, the introduction to this report, describes the goals and objectives of the SAST, the methodology used to meet the goals and objectives, some of the products, existing and planned, of SAST database building and analysis efforts, and a description of the study area.

Chapter 1

INTRODUCTION

PURPOSE OF THE PRELIMINARY REPORT

This preliminary report of the Scientific Assessment and Strategy Team (SAST) is Part V of the Interagency Floodplain Management Review Committee (FMRC) report, Sharing The Challenge: Floodplain Management Into The 21st Century. This preliminary report documents much of the scientific information provided by the SAST for use by the full FMRC in its deliberations and summarizes SAST activities to date. The scientific assessments and analyses presented in this report are preliminary and have not received full critical scientific review. A comprehensive report is planned that provides detailed documentation of the analysis, mapping, and database activities conducted by the SAST. The level of detail in this preliminary report is uneven as a result of different levels of detail that were required for FMRC deliberations on specific topics and time limitations imposed on the FMRC. The preparation of this preliminary report is in partial completion of the goals and objectives of the SAST. A partial list of the other scientific and technical products provided to aid FMRC analysis is included at the end of this document (Appendix A.).

GOAL AND OBJECTIVES OF SAST

The flood of 1993 in the Upper Mississippi River Basin had peak discharges at many locations that exceeded any other peak discharges on record for those locations (Parrett and others, 1993). Although floods of the magnitude and duration of the 1993 event are rare occurrences, they are natural and will recur. The human and economic costs were high; yet, there were ecological benefits, such as improved spawning areas for some fish species and reconnection of some backwater areas to the channel. The negative and positive effects of the flood raised old concerns about flood control measures and habitat restoration. The Scientific Assessment and Strategy Team (SAST) was formed to help decision makers address those concerns by providing scientific advice on flood recovery and future management of the floodplain.

While the SAST was charged with focusing on floods and the structural and nonstructural methods of river basin management, the SAST members acknowledge that any action designed to adapt to or mitigate flooding must also take into account adapting to or mitigating low flows.

Further, sustainable development of the river basin is considered in the gathering of scientific data and in scientific analysis.

The goal of the SAST is to provide scientific advice and assistance to Federal officials responsible for making decisions with respect to flood recovery in the Upper Mississippi River Basin and to develop and provide information to support the decision making process regarding both nonstructural and structural approaches to river basin management. The SAST objectives are

to develop a database of readily available data to support map production, scientific analysis, and decision making;

to produce maps showing base information and vulnerability to flooding; and

to prepare reports documenting the products of SAST and the methodology and analysis used to produce them, and identifying the ongoing monitoring, research, modeling, data-management and distribution requirements needed to support integrated river basin management.

THE SAST

The SAST was established on November 24, 1993, by directive of the White House Assistant to the President for Science and Technology Policy, the Office of Management and Budget, and the Office of Environmental Policy (Appendix B). The SAST is an interdisciplinary team composed of senior scientists and engineers from the Department of Agriculture (Soil Conservation Service), Department of Defense (U.S. Army Corps of Engineers), Department of the Interior (Fish and Wildlife Service, National Biological Survey, U. S. Geological Survey), Environmental Protection Agency (EPA), and the Federal Emergency Management Agency (FEMA). The SAST joined the FMRC on January 10, 1994, by directive of the Office of Management and Budget (OMB), Office of Environmental Policy (OEP), and the Department of Agriculture (USDA). The SAST has responsibilities to support the FMRC with information and advice and also has responsibilities independent of the FMRC to obtain, organize, analyze, manage, and distribute scientific data and information as well as provide advice to policy and management decision makers. As part of the FMRC, the SAST has also participated in preparation and review of the report of the FMRC to the Administration Floodplain Management Task Force.

There are 19 full time SAST members, 6 associate members, numerous ad-hoc members, and 3 project staff members. Initial funding was provided by FEMA with follow-on funding provided through two supplemental appropriations to the U.S. Geological Survey (USGS). Salaries are borne by the home agencies of the scientists and engineers involved. Significant in-kind support is provided by all of the agencies involved. In-depth technical and scientific support is provided by the Earth Resources Observation Systems (EROS) Data Center (EDC). States and a number of nongovernment organizations have been helpful as well by providing data, information, and analysis. Contributors are listed at the end of this report (Appendix C).

The SAST met at EDC near Sioux Falls, South Dakota, for an initial workshop during the week of December 13, 1993, to identify the scope of the problem and to begin to address the many logistical issues that the team would encounter. It began concentrated efforts at EDC on January 3, 1994, and continued until March 11, 1994. Since that date, the SAST continues to function as a distributed team with members working at their home offices or laboratories. The team also conducts workshops to address specific issues.

While at EDC, the SAST built a vast multilayer, multiresolution database covering the Upper Mississippi River Basin. The data densities vary spatially depending on the intensity of study that is required of the SAST. The most concentrated and complete data are along the floodplains of the upper Mississippi and lower Missouri Rivers because these floodplains represent the areas of most immediate interest to policy makers dealing with questions about response to the 1993 flood, the Federal levee system, and habitat restoration. The data are most sparse on the Upper Missouri River Basin upstream of Gavins Point, South Dakota. The primary purpose of the Upper Missouri River Basin data sets is to form a baseline of data and information for future studies since that area did not contribute appreciably to the flood of 1993. Intermediate data densities are in the areas that contributed to the 1993 floods. The database contains advanced very high resolution radiometer (AVHRR), Landsat Thematic Mapper (TM), and other satellite data, elevation data, selected digitized photographs, historical channel geometries, artificial structures, geologic, biologic, hydrologic, hydrographic, hazardous/toxic, and soil survey data, and data on many other topics.

Some of the SAST products include special maps, demonstrations of data applications, decision rules for identifying high priority habitat sites, methods for identifying reasonable alternative levee locations, and new understanding of the influence of variables such as focused flood-flow energy, the relationship between historical and current channel and sedimentation and scour, and land use on the impact of floods on the lower Missouri and upper Mississippi floodplains. The use of these products for management and decision making will be the subject of future scientific and management activities.

Data to populate the database and information for the preliminary report came from many sources including Federal agencies, state governments, universities, and nongovernment organizations (private industry and interest groups). Most data sets were modified from existing available data to make them intercomparable, to format them uniformly, or to otherwise improve their quality. Due to time limitations, many problems encountered in the data were identified in the metadata and not corrected when entered into the database. Quality assurance is an ongoing effort (see Chapter 2). Many data sets that were in the form of maps and tabular listings were digitized and included if they were useful for answering questions raised in the decision making process. Some data sets were built completely from scratch because of the critical need for them and their lack of availability.

APPROACH

To use the scientific method, observations must be made, hypotheses should be made based on those observations, and the hypotheses should be tested by determining how closely responses of the natural system to forcing functions correspond to predictions. Typically, there is an iterative cycle of refinement of the understanding and predictions. The system must be monitored to gather successive data on the observable variables. Those data must be compared to the predicted values of the variables.

The approach consisted of identifying potential questions that must be answered to support integrated river basin management, identifying the data needed to answer those questions, identifying sources for those data, acquiring those data and incorporating them into a compatible database, conducting analysis with the data, identifying additional data needs or developing results from the analysis, and when necessary, acquiring additional data.

It has been clear for many years (Changnon and others, 1983) that incomplete and inconsistent collection of data is a severe handicap to developing policy for floodplain management. In recent years, technology has been developed that aids in data analysis. Geographic information systems (GIS) and image processing systems provide powerful analytical tools that can aid research and assessment of river basin management on local to regional scales. Computerized process models provide a method of estimating process change under different conditions. Time-series analysis and visualization techniques provide methods to understand great amounts of data associated with events. Still, data acquisition and database development are the most difficult and expensive parts of implementing these modern technologies. In this case, for the management of the Upper Mississippi River Basin, a significant amount of data has been acquired already. These data include historical land use and land cover, historical river channels, precipitation, river flows, and many others. However, most of these data are not in digital form and must be digitized. In many cases, where the acquired data are in digital form, they are not in compatible formats; these data are also in the process of being converted. In addition, certain necessary data did not previously exist. These had to be interpreted from aerial photographs or satellite images, collected in the field, or otherwise acquired.

The database was the central focus of initial activities because analysis could not begin until sufficient data were available. The objective of the first analysis was to identify gaps in the original estimation of data needs. These needs were then satisfied either by acquiring additional existing data or by conducting field, remote sensing, process, or modeling analyses.

PRODUCTS

Products from the database include data, maps, illustrations, analysis results, and statistics. These are provided to policy makers as they become available. The generation of these products further refines the understanding of the process and aids in developing decision rules for scientific river basin management.

Ultimately, the results are reported. The SAST is producing a multivolume report that provides scientific information and makes recommendations. The volumes of this report are as follows:

Volume 1. **Preliminary Report** documents general scientific background and specific narrowly defined analyses provided to the full FMRC for use in deliberations to produce the Report of the Interagency Floodplain Management Review Committee to the Administration Floodplain Management Task Force,

Volume 2. **Scientific Report** documents in-depth analysis conducted by the SAST using existing and newly developed data and techniques to provide improved understanding of scientific information for river-basin and floodplain management. Techniques, understanding, and management recommendations are presented to aid policy makers and resource managers. This report is currently unfunded.

Volume 3. **Database Report** provides a detailed description of the data and database for users. This includes metadata, descriptions of the strengths and weaknesses of the data, acquisition methods, data maintenance plans, and data distribution methods,

Volume 4. **Scientific Background Report** contains the papers and study reports that were commissioned by the SAST to answer specific questions. These papers will be published to ensure that this publicly funded analysis is readily available to the public, and

Volume 5. **Proceedings of the SAST Hydraulic, Hydrologic, and Ecologic Modeling Workshop (February 15 & 16, 1994)** contains papers presented by workshop speakers and selected discussions of the workshop participants.

Additional reports and scientific papers will be published in the scientific literature as they become available.

GEOGRAPHIC DESCRIPTION OF THE UPPER MISSISSIPPI RIVER BASIN

The Upper Mississippi River Basin consists of areas drained by the Mississippi River above the confluence with the Ohio River at Cairo, Illinois. It includes the entire Missouri River basin, which joins the Mississippi above St. Louis and extends west to the Continental Divide. The Missouri River and its tributaries drain most of the northern Great Plains. The Upper Mississippi River Basin covers 23 percent of the conterminous United States, an area of 700,000 square miles. The entire Mississippi River basin drains 1,270,000 square miles, or 41 percent of the conterminous United States.

The states that are entirely or partly contained in the SAST detailed study area are Iowa, Missouri, Illinois, Wisconsin, Minnesota, North Dakota, South Dakota, Nebraska, and Kansas. The SAST detailed study area lies almost completely in the Central Lowlands physiographic province, with small areas in the Ozark Plateaus and Superior Uplands provinces. Figure 1.1 illustrates the geographic extent of the study area.

For issues related to floodplain management and the areas most severely affected by flooding in 1993, three smaller study areas were identified. These are 1) the main stem of the Mississippi River above Cairo, Illinois, 2) the main stem of the Missouri River below Gavins Point Dam near Yankton, South Dakota, and, for most of the issues, 3) the main stem of the Illinois River. For the SAST study, the lower Missouri River extends from the Gavins Point Dam near Yankton, South Dakota, where the river enters the Central Lowland physiographic province, to its confluence with the Mississippi River at St. Louis, Missouri. Gavins Point Dam is considered the upstream boundary of the detailed study area because that dam significantly limited the contributions of the upper Missouri River basin to the flood of 1993. Defined more precisely, this area excludes the Missouri River above Fort Randall Dam and the upstream reaches of the western tributaries to the Missouri River -- the Platte and Osage Rivers. It includes the Big Sioux, Vermillion, and James Rivers, and the lower reaches of the Kansas, Platte, and Osage Rivers.

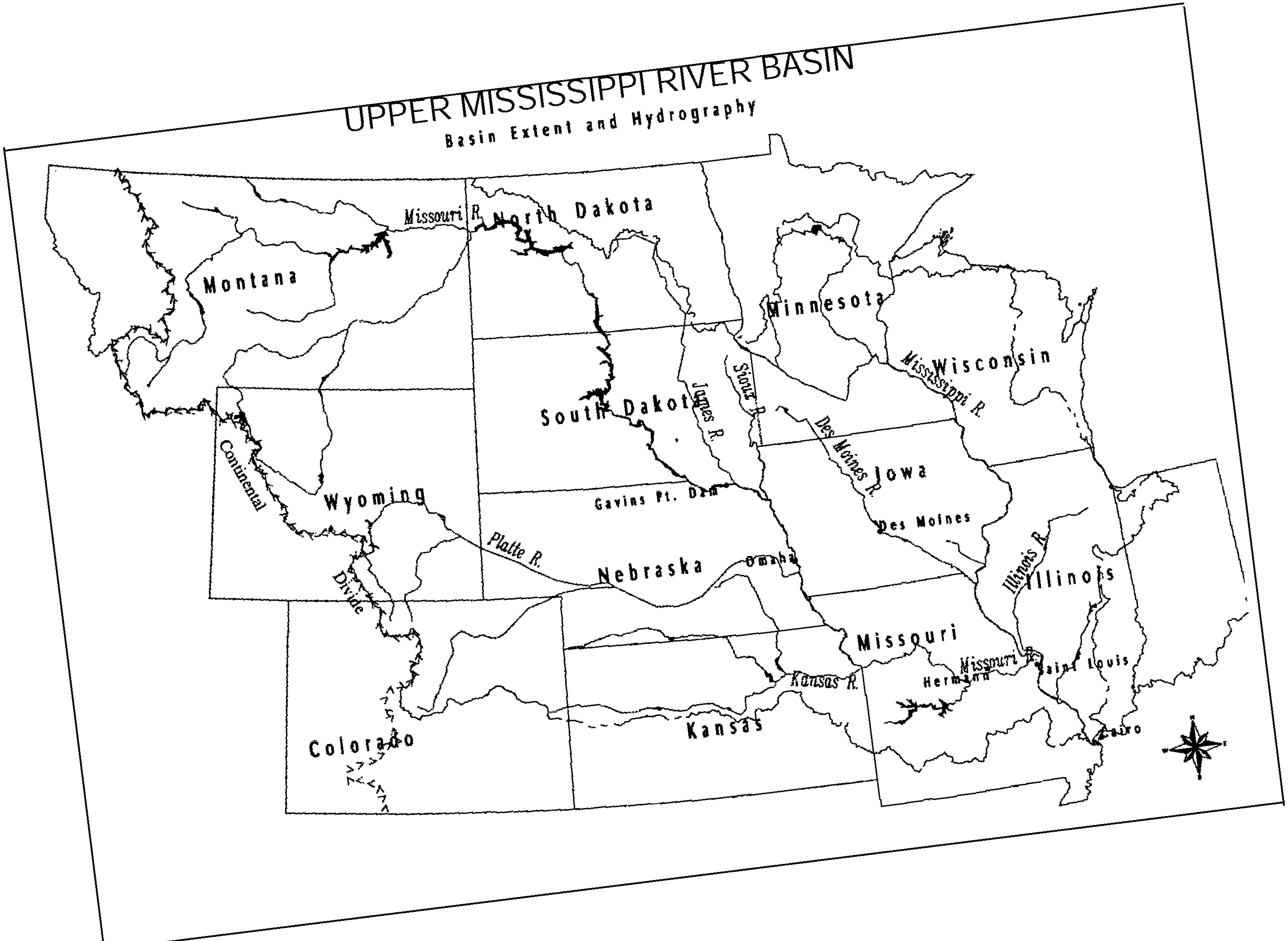

UPPER MISSISSIPPI RIVER BASIN
Basin Extent and Hydrography
Montana
North Dakota
Missouri R.
South Dakota
Minnesota
Wisconsin
Mississippi R.
James R.
Sioux R.
Des Moines R.
Iowa
Des Moines
Gavins Pt. Dam
Wyoming
Continental
Divide
Platte R.
Nebraska
Omaha
Illinois R.
Illinois
Missouri
Missouri R.
Saint Louis
Hermann
Kansas R.
Kansas
Colorado
Cairo

Figure 1.1

The geographic setting of the Upper Mississippi River Basin is described in many general reference works. For the description here, climate data are from Baldwin (1973) and drainage areas, river miles, and elevations are from the published records in the annual USGS Water Data Reports. Useful summaries of surface water hydrology, floods, and droughts in the Mississippi River basin (and throughout the nation) are given in National Water Summary reports published in the USGS Water-Supply Papers (Moody and others, 1986; Paulson and others, 1991).

The area of the Missouri River drainage basin above Yankton is about 280,000 square miles; the area at the mouth at St. Louis is about 526,000 square miles. (These areas exclude about 3,000 square miles of noncontributing area in the Great Divide closed basin.) The lower Missouri River flows about 800 miles from Yankton (river gage datum elevation 1,140 feet above sea level) to the mouth at St. Louis (400 ft), with a nearly uniform slope of about 0.9 feet/mile. The mainstem floodplain ranges from about 2 to 10 miles in width; it is relatively narrower in the last 200 miles of the river's course than upstream. The total area of the lower Missouri floodplain is about 2 million acres (3,100 square miles).

Most of the drainage area of the Missouri River is in the Great Plains. Average annual precipitation depths range from less than 12 inches near the Rocky Mountains to about 24 inches in eastern South Dakota and 32 inches in eastern Kansas; average annual precipitation increases to about 39 inches near St. Louis. Most of the precipitation occurs in the summer, late spring, and early fall months. Mean annual pan evaporation greatly exceeds precipitation throughout most of the basin. Mean annual runoff for the mainstem lower Missouri River is correspondingly low, ranging from 1.35 inches at Yankton and Omaha to 1.99 inches at Hermann, Missouri, the lowest gage on the Missouri River (mile 97). The high runoff season is in the spring, when precipitation and snowmelt are high, soil is bare, and evaporation losses have not yet increased to their high summer levels. The seasonal distribution of flow in the main stem is heavily regulated for navigation, power generation, and flood control purposes by six major reservoirs in the upper basin above Yankton. About 1/3 of the flow at Hermann is derived from the drainage area between Kansas City and Hermann, which amounts to about 1/8 of the total basin area. Mean annual runoff from the smaller tributary basins ranges from about 3 to 5 inches in western Iowa and eastern Nebraska to 10 - 15 inches in central and southern Missouri. The SAST detailed study area covers 270,000 square miles and parts of 9 states, but some data have been collected and analysis has been conducted for the other parts of the Upper Mississippi River Basin because those data and analyses help explain the processes in the detailed study area.

The Missouri River drains 73 percent of the Upper Mississippi River Basin, but contributes an average of 36 percent of the total streamflow from the basin. Long-term average streamflow of the Missouri River at Hermann, Missouri, is 72,000 cubic feet per second (cfs), compared to 198,000 cfs for the Mississippi River at Thebes, Illinois, about 20 miles upstream from Cairo (Moody and others, 1986). Peak flows during the 1993 floods were rated at 750,000 cfs at Hermann and 975,000 cfs at Thebes (Parrett and others, 1993).

The area drained by the upper Mississippi River extends from Lake Itasca (elevation 1467 feet above sea level) in northern Minnesota to the mouth of the Ohio River at Cairo, Illinois. For about 660 miles between Minneapolis-St. Paul and St. Louis, the river flows through a series of navigation pools controlled by a total of 29 locks and dams. The average river slope is about 0.5 feet per mile between St. Paul (river mile 839 above Cairo, gage datum elevation 684 ft) and St. Louis (mile 180, datum 380 ft). Between St. Louis and Thebes, Illinois, the lowest gage on the upper Mississippi (mile 44, datum 300.00), the river is undammed and has a slope of about 0.6 feet per mile.

The drainage area of the upper Mississippi River (excluding the Missouri River basin) lies in the continental humid climate zone. Mean annual precipitation is about 24 to 30 inches in southern Minnesota and increases to about 44 inches near Cairo. Precipitation is concentrated mainly in the summer, late spring, and early fall months. Mean annual runoff of the upper Mississippi River is between 7 and 8 inches upstream from St. Louis and between 3.5 and 3.8 inches in the middle Mississippi River downstream from the confluence of the Missouri River. Although the upper Mississippi River is dammed for navigation between St. Paul and St. Louis, the water storage capacity of the pools is small, and, in contrast to the case on the Mississippi River, the dams have negligible effect on flood flows and seasonal distribution of runoff. Average annual runoff depth from small tributary basins ranges from about 3 inches in southwest Minnesota to 6 inches in central Iowa, to about 8 - 10 inches in Illinois, to 10 - 12 inches in Wisconsin, paralleling the trends in pan evaporation and precipitation and incorporating the effects of varying landforms, soils, and surficial materials.

Section II

DATA

One of the initial activities of the SAST was to acquire relevant existing data and integrate those data into a spatially referenced database. During that process, the SAST found that some data vitally important to making informed management decisions on the floodplain were not readily available, or were not uniformly acquired throughout the floodplains or river basin. These essential data included levee locations and major attributes, high-energy flood zones, and detailed economic data in the floodplains. Some of these data have already been acquired by the SAST while others, because of limited time and resources, remain for follow-on activities.

Section II describes the data aquisition activities and provides some insight into the data that have been collected by the SAST. Brief descriptions are given of the planned data management and distribution activities.

Chapter 2

DATABASE DEVELOPMENT

SAST DATABASE

In an information-based society, both spatial and aspatial data and information are critical to decision making. Because of its responsibility to build an effective regional database, the SAST also bears some responsibility for shaping long-term policy on many issues and has the opportunity to set an example as a prototype for a comprehensive, technology-based (remote sensing, GIS, process modeling, time-series analysis, visualization), Federal approach to planning and emergency preparedness. The SAST focuses much of its effort on the planning, creation, and organization of a geographic database that will be available across agencies and levels of government.

This section describes SAST database efforts planned through September 1994. Before, during, and after the flood of 1993, many agencies were involved in routine or specialized data-collection efforts. Almost every agency in the affected area has undertaken studies of the flood as it affects agency interests. Because of limitations in resources and time, and despite continuing outreach efforts of the SAST for data collection and coordination, it is likely that new sources of valuable information will continue to surface.

In general, database efforts follow two tracks. One is the compilation of existing digital data for large geographic areas. The other is the creation, often involving previously uncompiled data, of very specific data and analysis for the floodplain, especially data related to levees.

THE SPATIAL DIMENSION OF INFORMATION

Many definitions of GIS have been written (Maguire, 1991) and most definitions fall into one of three overlapping categories: 1) map, 2) database, and 3) spatial analysis. Although a GIS can be manual (Starr and Estes, 1990), modern GIS is considered to be computerized. For SAST purposes, a GIS is considered to be computerized. Because of the spatial extent, complexity, and potential variety of uses, the SAST GIS fits into each of the defining categories. First, it is a method of digitally storing geographic data and producing useful map products from those data. Second, it is a large database and database management system that contains both spatial and aspatial data that will be of value to management decision makers and scientific analysts alike.

Third, it is designed to enable analysis. The analysis conducted with it has already provided valuable information for policy and management decision making.

Technologically, a GIS is described as a system of hardware and software, procedures, and data that can be related to their place on the Earth, and with which analysis can be conducted. A GIS database typically consists of a set of layers, coverages, or themes of data, each of which describes the spatial distribution of some feature or attribute.

Two basic spatial data structures are used in a GIS database, vector and raster. A vector structure stores data or features as points, lines, or polygons that are defined by a set of Cartesian coordinates. Each feature in a vector layer can have many attributes associated with it -- a vegetation layer may have attributes for dominant species, crown height, canopy cover, and so on. A raster structure stores data as a regular array of cells, such as in satellite image data, or in generalized data that could be obtained by laying a grid over the landscape. Typically, single theme data in a single raster cell, or pixel, are given a single value.

In this report, the term 'coverage' refers to a raster or vector-based GIS data set that corresponds to a single theme, or layer. It is the principal storage unit for the SAST database. Spatial data can be tied to a location; geospatial data can be tied to a location on, in, or above the Earth. Relational databases, such as spreadsheets or time-series, often can be tied to a point, line, or an area, and thus become attributes of the GIS coverage. Time-series data are important because they provide an opportunity to relate changes in one phenomenon to changes in another, offering insights to causal relationships, trends, and event frequency that could not be identified or interpreted any other way.

DEVELOPMENT OF DIGITAL DATA

Obtaining Data

- When the SAST met in December 1993, the team developed a list of data sets that are critical for assessing impacts of the flood, responding to the flood, planning for floodplain management, and planning for river basin management. This list was refined as time went on and as the database was built. Some of the data were relatively easy to obtain, such as Landsat Thematic Mapper (TM) satellite data and 1:100,000-scale digital line graph (DLG) data, because their existence is widely known and there is an established, accessible distribution mechanism. Other data sets were more difficult to obtain because no clearing house or defined point of contact existed for information about the data.

Recommendation 2.1: Establish an interagency clearinghouse for data relevant to monitoring and managing the Upper Mississippi River Basin. This clearinghouse should

be part of the National Information Infrastructure (NII) and should be well integrated with the various components of the NII, such as the National Spatial Data Infrastructure (NSDI), the proposed National Biological Information Infrastructure (NBII), and other thematic data infrastructures as may be established.

This clearinghouse should test advanced clearinghouse concepts and provide feedback to the Federal Geographic Data Committee (FGDC) for its planning of other clearinghouse activities on the national level. This clearinghouse should include Federal agencies, state governments, tribal and local governments, and nongovernment organizations as appropriate.

The interdisciplinary, interagency nature of the SAST is a primary reason it is effective in identifying the wide variety of data that have been collected and continue to be collected. In addition, the excellent cooperation of scientists and managers at the state level is invaluable in building the database and analyzing the data.

Recommendation 2.2: Establish a permanent interdisciplinary team of senior scientists from the Federal and state governments to coordinate data acquisition, analysis, and research to support management and policy decision making for the Upper Mississippi River Basin. Membership on this team should be for a limited term (3 to 5 years) and members should rotate.

In spite of the excellent cooperation that took place among agencies, there were still some difficulties in obtaining data.

- Making the right contact: In many cases, considerable effort was required to determine what data are available and how best to obtain them.

- Getting cooperation: Generally, most organizations were cooperative within the limitations of their resources. Many went beyond what normally would have been expected because of their understanding of the future value of the database. At times, however, there were misunderstandings about data needs and availability. The intense and short-term nature of the SAST database building activity occasionally made communications with various organizations difficult. To overcome the time limitations, normal chain of command communications were bypassed. This bypassing occasionally caused misunderstandings as well. For activities of the type that the

SAST conducted, a notice should go out to the top executive level of all agencies from the organization establishing the activity to notify the agencies of the need for cooperation.

- Establishing transfer protocols: As was anticipated, the SAST received data from a wide variety of sources, in many different formats, and by a number of transfer methods. The SAST received spreadsheets, ASCII files, data in agencies' unique formats, and data in proprietary format. The SAST received data on floppy disks, on 8-mm tapes with various densities and blocking factors, on cartridge tapes, on 9-track tapes, on CD-ROM's, via Internet, in packages, and in hardcopy form. This wide variety of data transfer formats, though time consuming and costly to deal with, often is the norm when dealing with large varieties of data.

Recommendation 2.3: Government and nongovernment organizations should migrate their data to standard transfer formats and structures as the formats and structures become available.

- Locating special data sets: Some data sets stored or maintained by government agencies were known only to the few people who used them in their immediate projects. It is likely that many such data sets exist that were not identified by the SAST. An example of one such highly valuable data set is the post-flood aerial photographs of the Missouri River taken by the USACE. These types of data were identified during workshops or discussions with government or nongovernment personnel. Identifying these types of data is often done by chance and acquiring them is often time consuming.

Recommendation 2.4: Organizations producing data sets, even if the data sets are specialized or limited, should list those data sets in the clearinghouse for informational purposes. In times of emergency, these data sets can have broad value.

- Receiving data: Some data promised to the SAST were never released by the originating organization. For other data sets, release came only after frequent contact with the organization. Occasionally, personal visits to organizations were necessary to acquire the data. This situation could be alleviated by having agencies maintain their data for distribution either online or through normal distribution channels accessible through a clearinghouse.

- Cost of data: Some data cost more than the team could afford, were proprietary, or had such severe limitations on their use that purchase was inappropriate.

Recommendation 2.5: Where important data are not within the purview of the Federal government or cannot be maintained or distributed by government organizations, pointers to appropriate nongovernment data could be used in the clearinghouse. The data could be acquired by users from the producer on an as needed basis.

- Lack of data: Some data did not exist, or did not exist in the appropriate form. Where these data were critical, they either had to be created or they would not be available for analysis. This data creation required considerable effort by the SAST, by contractors, and by government and nongovernment organizations.

Developing new data sets in the short time that was available for the initial SAST activities at EDC required initiative and follow through. For instance, while building the levee database the SAST received input from a variety of sources: levee information forms were produced and distributed widely, and low quality maps and sketches were obtained from the disaster field offices. This information was transferred to better source material and field work was conducted in some areas. A considerable digitizing effort was necessary to compile the data. Because the initial information came from a variety of sources and had inconsistent and often only partial or erroneous attribution, a quality assurance effort is underway involving several agencies.

Compiling Data

Compiling data from a variety of sources is a challenging and often difficult task. Data acquired at different locations or different times or by different organizations often have inconsistencies in spatial accuracy and attribute values. Clearly, compiling data will be an ongoing task that requires continual attention in compilation, quality control, and quality assurance. Some of the issues addressed by the SAST during the initial phase of data compilation include the following:

- Spatial incompatibility and inappropriate resolution: Many data sets are spatially incompatible for the meaningful analyses that should be done. For instance, many of the economic data are maintained at the county level and are difficult or impossible to disaggregate to sub-county units, such as the floodplain within the county. This makes meaningful analysis of economic losses in the floodplain difficult or impossible. More detailed data could be obtained, but with great difficulty at the Federal level. If sub-county economic analysis or analyses based on physiographic regions that cut across county boundaries are to be done, data must be collected, maintained, and distributed at the appropriate scale and data density. Logical economic units would be levee protection areas, river side and mile, and census block.

Recommendation 2.6: Identify specific high resolution data needs, develop standards and specifications for the data, and develop cooperative arrangements with organizations that would have the capability and logical need to acquire those high resolution data for other purposes. These organizations would often be state and local governments.

- Data format and structure variability: Many data sets were in different formats and structures and had to be made compatible before they could be compiled into single data sets. These conversions are documented in the metadata. In some instances, there were insufficient resources available to make the conversion in a timely manner for initial SAST activities.

  - Data conversion: A number of data processing and conversion methods were obtained or created. A database structure was established, with standardized naming conventions and definitions. There were problems with combining coarse with detailed data, with understanding how one data set was similar to or different from another, and with handling updates to data that the SAST had already processed. For example, time-series data require structure and format that are inherently different from those required by other data.

  - Varying standards: Varying standards for data cause difficulties. Even within the same agency, different offices have entirely different approaches to data acquisition and management. Some use structured GIS databases, some use paper maps, and some maintain their data in random form. While it is not the responsibility of the SAST to assist in the internal workings of agencies or offices, the SAST does recommend that agencies and offices standardize their data collection and storage procedures to improve internal organizational operations. These standards should meet accepted exchange formats and standards so they will be readily exchangeable in an interorganizational environment.

- Data initially produced in different organizations frequently have different definitions for attributes, different accuracies and reliabilities, and different collection and storage methods. The differences are often the result of the data being collected for different purposes. This range of differences made converting these data to a compatible format difficult and costly for the SAST. One way of reducing incompatibilities is to ensure that there is an adequate framework data set to which other data sets and analysis can be tied. There should be a spatial data framework and thematic framework as well.

Recommendation 2.7: Develop and maintain a framework data set for the river basin. The framework should form the basis upon which other data could be related and registered. This framework data set should contain physical spatial data, biological/ecological data, social data, and economic data to which other data sets could be attached, registered, compared, and analyzed. In addition to standard recommended framework data, such data as river miles, levee locations, and physical features such as bluff location, should be included.

- The compilation effort required extraordinary coordination during the initial phase of activities. All compilation tasks had to be completed by the same limited staff and because of the short time-frame in an "emergency" effort, each task seemed to have high priority. Preparations should be made in advance, not only for flood emergencies in the Upper Mississippi River Basin, but for elsewhere and different emergencies. Those preparations would require ongoing advance data acquisition and compilation and techniques development. Thus, the clearinghouse (recommendation 2.1) would form a basic component of emergency response but would be continually augmented by the development of new relevant data. Emergency response would also be served well by having techniques for applying these data developed in advance.

Recommendation 2.8: Establish an interagency interdisciplinary group of scientists to continually refine and develop relevant data and techniques to assist in flood mitigation and response. The group should be coordinated by FEMA, USACE, and USGS and should include agencies such as NWS, TVA, SCS, and others as appropriate. Similar groups should be established for other types of emergencies.

Analysis

- Data analysis is necessary to test data, develop and test hypotheses, improve understanding, and provide information to management and policy decision makers. The

SAST has only begun to conduct data analysis. In addition, research and analysis are being conducted by many agencies independent of SAST activities. Using the data for analysis helps improve knowledge of the accuracy and attributes the data should contain. This information is needed for updating the data. Such analysis will result in improved data and understanding useful for management of the river basin and floodplain.

Recommendation 2.9: Provide funding for the SAST to conduct initial analysis and research using the data during FY 1995. Instruct agencies to request funding for continued analysis in their FY 1996 budget request.

- Because of the short time available and the many tasks required of the SAST, a full inventory of research relevant to Upper Mississippi River Basin flooding could not be conducted. Such an inventory would be useful to help identify research needs, gaps, and overlaps and would help direct funding more efficiently.

Recommendation 2.10: Conduct a crosscut of Federal agency data acquisition, analysis, research, and scientific information distribution activities of benefit to river basin and detailed floodplain management for the Upper Mississippi River Basin (and potentially for the Nation) under the auspices of OSTP and OMB.

DATABASE CONTENTS

The SAST is building its database by 1) obtaining existing digital data, both standardized and custom; 2) converting existing data from one form to another; 3) automating data from paper documents or maps; 4) interpreting original source data (aerial photographs, satellite images, field notes, and measurements) to form analytic data sets, and 5) combining or analyzing existing data to form new data sets. Data were compiled from a number of sources, at a variety of scales, and in many formats which were designed for widely different purposes. The principal coverages and the ones that are closest to final form are discussed here. Others will be incorporated as time allows.

A separate report documenting the database will describe individual layers in more detail and will include a more comprehensive list of data than the one included in this report.

National Geospatial Databases

A number of existing, nationally available geospatial datasets were obtained and compiled into SAST GIS coverages. Many were available through Federal sources, such as USGS Earth

Science Information Center. Some were obtained from commercial vendors; others were freely available to the scientific community.

Hydrography and transportation layers at 1:100,000-scale were obtained as ASCII files in digital-line-graph (DLG) format and were processed into coverages. Layers include hydrography lines (streams), areas (lakes), and points (springs); roads and trails; railroads; and powerlines and pipelines. Each 30 x 60-minute quadrangle for each layer is a separate coverage. Coverages for about 140 quadrangles are currently in the database.

Reach-File-3 (RF3) data, which contain detailed spatial and attribute data for rivers and streams, were obtained as existing coverages for the entire Upper Mississippi River Basin. The line work is based on the DLG hydrography but with different attributes and is grouped by hydrologic unit rather than by quadrangle.

Land use/land cover (LULC) data at 1:250,000-scale were obtained as ASCII files in GIRAS format and processed into coverages. Data are a level-2 classification, based on imagery from the mid-1970's to early-1980's. Each 1 x 2 degree quadrangle is a separate coverage. Coverages for about 50 quadrangles are currently in the database.

Soil-survey data at approximately 1:250,000 scale were obtained from USDA Soil Conservation Service (SCS) as existing coverages for a 17-state area. The data, referred to as STATSGO, are generalized soil groupings, with a number of related attribute files.

Digital-elevation-model (DEM) data were obtained as existing grids (raster data sets) for the entire basin. The data had been compiled from 1:250,000-scale maps at a cell size of 3 arc seconds. A number of derivative grids have been created. A number of 7 meter RMSE DEM files were obtained.

Data from the AVHRR sensors were obtained as existing grids and clipped to the basin. These data have a cell size of 1.1 kilometers. The obtained data were already classified for various categories, including vegetation type and greenness index.

Digital data for 96 pre-flood Landsat Thematic Mapper (TM) scenes covering the entire river basin are included in the database. Twenty-five TM peak flood scenes and 25 TM post flood scenes of the area of detailed study were obtained. The Landsat satellite acquires repetitive data of the same location at intervals of approximately 16 days. These scenes provided a time series critical to understanding the dynamics of the 1993 flood. Each scene was received in a stacked grid format of six or seven sensor bands, with 28.5-meter cell size. In addition, several SPOT and ERS-1 satellite images were obtained.

Several national databases of point data with extensive attribute information were obtained. Some covered all states in the basin; some covered only those states in the detailed study area. Some were received in spreadsheet or ASCII format; others were processed already into GIS coverages. These include the National Inventory of Dams, highway and railroad bridges, USGS streamflow gaging sites, National Oceanic and Atmospheric Administration (NOAA) weather stations, and a variety of EPA-oriented waste or point-discharge sites. Data from the 1990 census, separated into block groups, were also received and processed. The census data contain statistics of population, housing, and income and are related in ARC by centroid.

A number of freely available national coverages were also incorporated into the database. These include average annual precipitation and runoff, surface geology, hydrologic units, standard quadrangle boundaries, state and county boundaries, and many coverages derived from 1:2,000,000-scale national maps.

Other National Databases

Some valuable national databases were obtained that were not in GIS format, but nevertheless could be related to features in GIS coverages. For example, county-based 1990 census data contain hundreds of attributes and can be related to county coverages by the Federal Information Processing Standards (FIPS) code. Data for the 1987 census of agriculture likewise were obtained and related to county coverages.

County level statistics regarding 1989 and 1993 tillage survey; 1992 and 1993 acreage planted, acreage harvested, yields, and production by crop; 1993 Agricultural Stabilization and Conservation Service (ASCS) payment data by category; ASCS disaster payments; Federal Crop Insurance Corporation (FCIC) payments; Farmers Home Administration (FmHA) emergency farm loans, and FmHA emergency housing loans were also obtained through USDA. After some processing, these were tied to FIPS codes and also related to county coverages. State totals of food stamps, surplus food distribution, SCS, Rural Electrification Administration (REA), and all other USDA expenditures have been obtained. Much of this emergency expenditure data is based on running totals. Final USDA totals will be obtained in late summer 1994.

Bureau of Economic Analysis (BEA) economic areas, state, and Federal economic data were obtained from BEA on CD-ROM. These include 1969 to 1992 data on personal income, employment, transfer payments, tax and non-tax payments, farm income, farm production and expenses, and commuting flows of earnings. The data also include projections of income and employment to the year 2040, and county-to-county commuting flows for 1960, 1970, 1980, and 1990.

Time-series data for selected USGS and NOAA streamflow and weather observation sites were obtained from those agencies. The data have been tied to point coverages of the sites.

A great many weather-satellite images and surface-analysis (weather map) images are available from NOAA or its affiliates. These have not been obtained, but would be a valuable addition to a comprehensive database of the 1993 flood.

Regional and Local Databases

Many sources of data contained valuable information on a regional or local scale. The SAST focused its data-creation efforts on layers directly related to the floodplain.

Various databases relating to the main river system have been obtained, and continue to be obtained, from various agencies. These include pool boundaries, river-mile points and associated attributes, forestry data, lock and navigation data. A set of Missouri River charts, for which the data were collected in 1879 and published in 1891, has been obtained and digitized. The charts include delineation of channels and land cover.

Several classifications in the floodplain have been derived from TM satellite imagery. This includes maximum extent of 1993 flooding, natural floodplain as determined by satellite imagery, and a level-1 landcover classification based on the scheme developed by Anderson and others (1972).

One hundred and five hundred year flood boundaries from Flood Insurance Rate Maps (FIRM) were digitized by a contractor. The existing paper maps were "rubbersheeted" to fit existing base maps, then digitized and appended into 30 x 60-minute quadrangles, or partial quadrangles in most cases. Forty quadrangles, covering the principal floodplains of the Mississippi and Missouri Rivers, were created.

Aerial photographs, pre-, during-, and post-flood; black-and-white and color; at 1:20,000- and 1:40,000-scales have been investigated or obtained from SCS and USACE. Several sets of photos have been obtained and are being used for analysis in selected areas to determine channel morphology and areas of scour and deposition.

Accurate and detailed knowledge of levees is crucial for understanding flooding and for responsible planning in the floodplain. Unfortunately, no single existing database, paper or digital, was either consistent or complete. The SAST undertook a major effort to create a comprehensive levee database. Data were obtained in digital and paper form from USACE and SCS. Data were digitized from maps. Questionnaires were distributed; local offices were visited; returned questionnaires and tables of data were automated. A substantial set of attributes was added to the coverage of levee centerlines. Work on the levee database continues, in the knowledge that it is the best and most comprehensive basin-wide compilation of levees along the upper Mississippi and lower Missouri River main stems. However, at the time of this preliminary report, considerably more effort is necessary to complete the attribute list and quality assure the data. An interagency quality assurance effort is underway including USACE, USGS and SCS.

Streamflow and Reservoir Storage Data

Water data are collected by the U.S. Geological Survey at more than 700 sites throughout the detailed study area (Condes de la Torre, 1994). Continuous records of daily-mean flows and instantaneous flood peak flows are collected at about 500 of these sites; partial records of annual-maximum instantaneous flood peak flows are collected at about 200 additional sites. Reservoir storage and elevation data are collected at a few sites. The records are updated throughout the year and are finalized and published annually in USGS annual water data reports for each state. Copies of these reports for the study area are in SAST files. The reports also are available for reference in many major libraries and can be purchased from the National Technical Information Service, Springfield, Virginia.

Selected portions of the USGS database have been transferred to the SAST. These data include

- daily flow data for about 50 long term sites on the mainstem Mississippi, Missouri, Illinois, and Des Moines Rivers, plus a few major tributaries,
- peak flow data for the 154 sites at which major 1993 floods were reported in USGS Circular 1120-A,
- daily-, monthly-, and annual-mean flow data through 1988 for selected long-term sites suitable for climate-variation studies (the Hydro-Climatologic Data Network, HCDN, Slack and Landwehr, 1992, 1993),
- daily reservoir storage data at major reservoirs in the study area for the 1993 water year.

Data for additional sites can be obtained from the USGS District offices for the states in which the sites are located or from the USGS National Water Data Exchange (NAWDEX) Program Office in Reston, Virginia. Information on location of streamflow gaging sites can be obtained from USGS annual water data reports or from the District or NAWDEX offices.

In addition to the basic flow data, a set of equations for estimating flood flows at ungaged sites has been developed by the USGS. The equations express the annual flood peak flow of a specified recurrence interval as a function of drainage basin characteristics. Drainage area in most cases is the most significant basin characteristic in determining the flood magnitude; in many cases it is the only significant characteristic. Different sets of equations apply in different states and different regions within some states, reflecting regional variations in flood characteristics. The equations generally are applicable to basins with drainage areas between about one square mile and a few thousand square miles. The equations have been developed over the years by individual USGS Districts and have recently been compiled into a software package called NFF, which runs on PC-compatible computers (Jennings and others, 1994).

In addition to the flow data, stage-discharge rating relations were obtained for a number of mainstem sites. These are printed tables that can be used to determine the water surface elevation (relative to local gage datum) for any given flow rate for the time period for which the rating is valid.

Climate Data

Historical data on monthly temperature, precipitation, and evaporation for NOAA/NWS climate divisions throughout the area of heavy rain in 1993 have been obtained from the Midwest Climate Center. These data cover the entire historical period through September 1993 for the following climate divisions:

Iowa 1-9	Minnesota 2 and 4-9	Nebraska 2, 3, 5, and 6
Illinois 1-6 and 8	Missouri 1-3 and 5	South Dakota 3, 7, and 9
Kansas 3 and 6	North Dakota 5 and 9	Wisconsin 1,2, 4,5, and 7-9

Daily precipitation and temperature data for April-September 1993 for individual observing sites in Iowa, Illinois, Minnesota, Missouri, and Wisconsin were obtained from the Soil Conservation Service National Technical Center in Lincoln, Nebraska.

Climate data are, as of March 1994, in a state of rapid development. The Soil Conservation Service and the National Climatic Data Center (NCDC) both are developing improved climatic data sets.

Biological and Ecological Data

Several data sets related to the biology and ecology of the basin and floodplains were collected by the SAST. Basin-wide data include the U. S. Fish and Wildlife Service's National Wetlands Inventory (NWI) data where available. These data were created from aerial photo interpretation of National High Altitude Photography (NHAP) program 1:58,000 color infrared aerial photographs, from which data were transferred via optical transfer device to 1:24,000-scale base maps and digitized. The data are not complete, but the SAST has contracted with the NWI program to automate all paper maps that were complete to date.

Another basin-wide data set collected by the SAST is a portion of the Natural Heritage Database developed by The Nature Conservancy (TNC). Point locations of sightings of rare, threatened, and endangered species, as well as species of special interest are in the database. The data have been generalized to four categories: vertebrate, invertebrate, plant, and community and are restricted to areas within six miles of the floodplains of the major rivers and tributaries. Restrictions apply on the release of these data through agreement with TNC.

The continental-scale North American Waterfowl Plan (NAWP) Joint Venture Areas were digitized. The NAWP is an international agreement administered by the U.S. Fish and Wildlife Service (FWS) in the United States to restore waterfowl populations in North America to levels existent in the 1970's. The Joint Venture Areas are waterfowl habitat areas of major concern.

Floodplain biological and ecological data sets include Resource Inventories created by the FWS for the Mississippi River at Gutenberg, Iowa to Cairo, Illinois. These data were from field information collected by FWS biologists that were compiled onto 1:30,000-scale navigation charts. Polygonal data themes include sport and commercial fishing areas, fish spawning areas, mussel beds, and important wildlife areas. Point data themes were heron and cormorant rookeries and eagle wintering areas. Similar, although less detailed, data were compiled for the SAST biologists for the Illinois and Missouri Rivers.

Some ownership data related to biology were collected. These data included all National Wildlife Refuges in the floodplains of the Mississippi, Missouri, and Illinois Rivers, as well as state lands and natural preserves in Illinois, Wisconsin, and Minnesota.

The National Biological Survey's Environmental Management Technical Center (EMTC) contributed several spatial data sets on the Mississippi and Illinois Rivers. These included detailed land cover/land use data developed from 1:15,000-scale color infrared aerial photographs taken in 1989. Areas include Pools 8, 13, 19, 26, and a reach from river miles 30 to 85 on the Mississippi River as well as the LaGrange Pool on the Illinois River. Historic data contributed by the EMTC include land cover/land use data from 1891 - 1894 created by the Mississippi River Commission. These are highly accurate data compiled onto 1:20,000-scale topographic maps. Areas covered are the same as the 1989 data. The EMTC also contributed a data set of land cover for the entire upper Mississippi and Illinois River created from TM data. This data set has a nominal cell size of 30 meters on a side and has 9 general land cover/land use classes.

The SAST automated land cover/land use data from 1879 maps compiled by the Missouri River Commission.

Recommendation 2.11: Establish an archive of biological data to be part of the clearing house. The National Biological Survey (NBS) should be the lead agency to archive existing biological data sets and to identify and develop basin-wide biological data sets to be used for inventory and modeling in the Upper Mississippi Basin. These objectives coincide with the goals of the NBS' Gap Analysis program as well as the overall mission of the NBS. Current activities by EPA to produce biological data sets for the region should be compatible with the SAST database and EPA should incorporate these data into the clearinghouse.

Critical Infrastructure

Critical infrastructure is defined as "*...structures, facilities and installations of the following type and function: (a) those that, if rendered unserviceable, would impose significant hardship on the public, or (b) those that, if flooded, would pose a threat to public health, public safety and/or the environment. Critical infrastructure could include, on a situation dependent basis, municipal drinking water facilities, wastewater treatment plants, interior drainage pumping stations, major highway bridges, major passenger and freight railroads, critical access roads running through or over floodplains, major airports, hospitals and related medical care facilities, electricity generating plants, and facilities that generate, store or dispose of hazardous, toxic, or radioactive materials.*" (see Part II, pg. 71)

While it is clearly important to have a good inventory of critical infrastructure and to determine its vulnerability to flooding, no unified database of critical infrastructure currently exists. Some critical infrastructure categories have been acquired by the SAST. These include (in ARC format): hospitals, bridges, railroads, roads, point source facilities, waste-water treatment facilities (for all nine states except for Nebraska, Missouri, and both North and South Dakota). In tabular form, the SAST has data concerning waste-water treatment facilities for all states, airports, and electricity generating plants. In flat file form, the SAST has data concerning drinking water facilities impacted by the flood of 1993 for all nine states except North and South Dakota. These data represent a first cut at features that can become critical under various circumstances depending on their location and the situation.

Recommendation 2.12: Develop critical infrastructure data sets to be incorporated into the SAST database. Data sets should be maintained by the agency responsible for the particular infrastructure. Each responsible agency should become part of the clearing-house.

Recommendation 2.13: Databases that are crucial to managing the watersheds should be upgraded to provide good quality point locations that are suitable for analysis. The tracking system of damage to all infrastructure should be improved to allow for a better reporting mechanism. The system should contain information on type of infrastructure, type of damage, frequency of flood related damage, and historic cost of repair.

The tracking system currently in place in 1993 produced data gaps that made tracking specific damaged structures difficult. For example, the SAST was unable to obtain a list of wastewater treatment plants impacted by the flood because disaster assistance payments were made to communities under general categories such as utilities. Thus, specific facilities could not always be identified.

Contaminants

The flood of 1993 highlighted the need for a comprehensive assessment of industrial and hazardous waste storage facilities within the floodplain. To address this need, the SAST acquired spatial data sets from EPA to determine the magnitude of the problem of facilities containing toxic and hazardous substances that occurred within the 1993 flood extent.

Overlay analysis of point source contaminants was conducted to determine the number of superfund sites and toxic release inventory sites that occurred in the floodplain and 1993 flood extent. EarthSat Corporation was contracted by FEMA to provide the floodplain and flood extent coverages to the SAST. The flood extent coverage used in this analysis was conducted for an area covered by 17 USGS 1:100,000 - scale quadrangles. This analysis represents flood extent only within the floodplains.

Recommendation 2.14: Analysis should be conducted by EPA, USDA, and DOI to determine if inundation caused mobilization or other problems with hazardous substances as a result of the 1993 floods. (USGS is already conducting some analysis on mobilization of hazardous materials; additional studies must be conducted related to specific sites.)

Superfund sites are contaminated sites on the National Priorities List that are scheduled for clean up under the Comprehensive Environmental Response Compensation and Liability Act. The locations of superfund sites were provided by EPA Region 5 (Minnesota, Wisconsin, and Illinois) and Region 7 (Nebraska, Iowa, Missouri, and Kansas). The superfund polygon coverages are accurate and useful for analytical purposes. The number of superfund sites impacted by the 1993 flood extent area is 34; the number of these sites occurring in the floodplain is 22.

The Toxic Release Inventory (TRI) was obtained by EPA Region 5 and contains point coverages of facilities that manufacture, process, or use a minimal amount of toxic substances (less than 25,000 pounds per year). The EarthSat coverages were used for analyzing occurrences of TRI sites in the flood extent and floodplain. The point data have good locational accuracy, having been recently updated, and is useful for analytical purposes. The total number of TRI facilities impacted by the 1993 flood is 97.

Permitted dischargers such as wastewater treatment plants are included in a database titled Permit Compliance System (PCS). Specifically, the permitted dischargers data in the PCS are included in the National Pollutant Discharge Elimination System (NPDES). These data were obtained in a spatial, digital format from EPA Region 5 for Minnesota, Illinois, Wisconsin, Indiana, Michigan, and Ohio, and from the State of Kansas for Kansas. Iowa supplied the spatial data for the wastewater treatment plant portion of the PCS, but not for other permitted dischargers. PCS data and NPDES data are available for Missouri and Nebraska (and all the states within the study area) in a relational database. This database must be translated to a spatial format to be useful for geographic analysis. The PCS and NPDES are not accurate in terms of specific point locations of occurrence and may contain gross errors.

Site specific information for public water systems is included in a relational database titled FRDS. These data can be translated to a spatial format. The locational accuracy for this data is not reliable and is further complicated by the fact that a single public water supply can be serviced by several wells separated by considerable distances. However, the SAST database has individual state lists of drinking water systems that were impacted by the flood of 1993 for the seven states in EPA Regions 5 and 7. These lists were provided by each state involved.

Another database maintained by EPA is the Resource Conservation and Recovery Information System (RCRIS), containing sites subject to RCRA. These sites include the location of incinerators, storage and treatment facilities, and disposal facilities. This information has not yet been made available to the SAST. The RCRIS data are important to analyzing impacts of the flood.

Recommendation 2.15: Conduct further study to determine how to protect the environment from hazardous materials either by reducing the risk of mobilization, or by neutralizing the effects of mobilization.

That information should be included in a digital spatial database accessible through the clearinghouse. The following activities are recommended: 1) locate all potential sources of hazardous waste in the floodplain, 2) investigate the SAST preliminary results concerning superfund and TRI sites within the flood extent and determine whether impacts occurred, and 3) make recommendations for avoiding hazardous waste impacts for future flooding events.

Elements of some EPA databases were found to contain inaccuracies such as disagreement between county locations and coordinates for sites. These databases include RCRIS, FEDS, PCS, and NPDES, and they cover more than 42,000 facilities in nine states in the flood study area.

Recommendation 2.16: EPA should upgrade the spatial accuracy of the RCRIS, FEDS, PCS, and NPDES databases to improve their usefulness for spatial analysis. These data should be maintained current and kept in an EPA node of the clearinghouse to ensure rapid and easy access by users.

Unpublished Reports, Proposals, and Plans

Many agencies have produced or commissioned plans and proposals on management, operations, and research topics in the Upper Mississippi River Basin. Some of these have not been published, yet they represent a considerable investment by agencies to gather information that is sometimes in greater detail than published material. Often, these documents contain scientific and engineering information that has value beyond their originally intended use. For example, flood control plans have been developed for watersheds and river reaches throughout the SAST study area by USACE and SCS. These plans contain detailed maps, hydrology data, and economic damage assessments; some may also be of value in analyzing ecological viability of a region. These plans are located in a variety of offices throughout the agencies. The information already contained in many of these reports could help reduce the cost of future activities to gather and analyze similar information. These documents should be cataloged and listed in a data directory that can be accessed through a readily available clearinghouse. The documents could be digitized for easy storage and automatic retrieval.

Recommendation 2.17: Plans, proposals, and reports that contain useful scientific, engineering, social, or economic data, information, and analysis should be listed on a widely used data directory. These documents should be made readily accessible to the user community. Listings should be retrievable by geographic location, topic, organization, and, for plans and proposals, outcome or implementation.

ORGANIZATION OF DIGITAL DATA

With any database so comprehensive, planning and organization are essential. The objective was to compile a variety of information that could be used by many people for many purposes, both now and in the future. The time-series data themselves have been stored in the SAST data directory in formats that can be used by standard time-series analysis software. Further study and analysis are required to identify and compute time-series summary statistics that would be suitable for storage in the ARC/INFO database and meaningful for spatial display and analysis. The following sections describe the initial structure of the database. As the database evolves, the structure will be improved.

Hardware, Software, and Data Formats

The SAST digital database was compiled and is currently stored on a computer network at the EROS Data Center. Currently, the database is approximately 240 gigabytes, including uncompressed satellite data. Accessibility to the database will be through online access for specific datasets and offline or near-online access for others.

The principal GIS software is ARC/INFO. All GIS vector-based databases, or coverages, are processed and stored in ARC/INFO format. Most of the raster-based data are stored in ARC/INFO GRID format. Raster data are processed using ARC/INFO GRID or LAS, which is an image-processing software system used at EDC.

Relational data, such as county-based census statistics, are stored in INFO files and incorporated into the ARC/INFO RELATE environment. These related data become part of the spatial database and are used for spatial analysis or display. Many of the relational data were received in the form of PC-based spreadsheets. Because many associates request the data in spreadsheet format, and because the data often undergo considerable manipulation during conversion to INFO, the original spreadsheet data are stored in a separate directory in DBase format.

Time-series data generally have not been fully integrated into the SAST database structure. As feasible, site-description information for sampled data has been converted into ARC/INFO point coverages. The time-series data for gaging stations and readings have been stored in the SAST data directory in formats that can be used by standard time-series analysis software. Further study and analysis are required to identify and compute time-series summary statistics that would be suitable for storage in the ARC/INFO database and meaningful for spatial display and analysis. There are many types of time-series data. For example, historical channelways are time-series.

Geographic Projection and Coordinates

All vector-based coverages were converted to an Albers equal-area projection that is commonly used for national maps. The projection uses standard parallels of 29° 30' 00" and 45° 30' 00", a central meridian of 96° 00' 00", and a latitude of origin of 23° 00' 00". No false northing or easting is used. In general, all coverages are stored in double-precision coordinates.

Thematic Mapper imagery was received in the projection corresponding to the local Universal Transverse Mercator (UTM) zone that applies for the extent of each satellite image.

Thus, different TM images may be stored in different map projections, ranging from UTM zone 12 in the west to zone 16 in the east. Because of the loss of information involved in projecting raster data from the source, the TM images were not projected into the standard Albers projection.

All other raster databases, however, were projected into the standard Albers projection. These include the DEM grids and their derivative products, and the AVHRR images.

All GIS data, including vector and raster formats, are stored in units of meters relative to the North American Datum of 1927. Elevations are based on the National Geodetic Vertical Datum of 1929. (The 1927 and 1929 datum were used since most data sets were already referenced to these.)

Naming Conventions and Item Definitions

Near the beginning of the data collection effort, standard nomenclature was established. This included criteria for the naming of computer directories and files, the naming of GIS databases, the naming of items in the databases, and the definitions of commonly used items. Due to the diverse nature of the database and the wide range of sources, not every database has been modified yet to meet these standards. A partial description of the standard nomenclature is presented in Appendix D.

Organization of Data Directories

Some vector-based coverages, tabular data, and time-series data are stored online on the SAST computer network. The database structure of the online directories will be discussed in the Database Report. This structure is expected to change somewhat as the database is finalized.

Due to the very large data storage requirements of the Thematic Mapper inventory of satellite imagery, it currently is not practical to store that entire database online. Only a sampling of those images is stored online. All the TM data are stored on 8-millimeter tapes, as ARC/INFO grids, archived in UNIX 'tar' format.

Documentation

For any collection of data, long term utility depends on adequate documentation. An informed analysis requires knowledge of the source, accuracy, method of creation, history of modification, known inadequacies, description, and purpose of the data at hand.

Work is underway to complete the documentation of the collective SAST database. A documentation program, developed for the Distributed Spatial Data Library (DSDL) of the

USGS, is being used for all major coverages. In order to obtain sufficient metadata, or documentation, for data received from outside sources, a documentation request form has been posted to all suppliers of data.

The documentation complies with the requirements of the National Spatial Data Infrastructure and the Federal Geographic Data Committee wherever appropriate documentation has been provided by the supplier of the data.

Quality Assurance

The quality of data in the SAST database varies greatly in all categories: spatial accuracy, timeliness, completeness, attribute accuracy and reliability. These variations can take place within a single data set or from one data set to the next. Sources of problems in quality also vary. The original source material may have been inaccurate or of low quality. During compilation or transformations, geographic, mathematical, format and structure errors may be introduced to the data. For the most part, the data were accepted from the source without significant attempts to improve quality.

While most data sets are of high quality as they were supplied, some clearly must have their accuracy improved to be useful for reliable analysis. The SAST generally will not upgrade the quality of databases created for purposes other than the SAST activities. However, a quality assurance activity is being conducted to gain some insight to the quality of those data as well as the data that were specifically produced by the SAST or for the SAST activity. Where feasible, the SAST will improve the quality of data; where it is not feasible to improve the quality, the SAST will document the findings of its quality assurance activities in volume 3 of the SAST report.

FURTHER DEVELOPMENT OF DIGITAL DATA

The SAST database will grow as additional data become available or existing data are identified and incorporated into the database. As additional cooperators are identified and agree to maintain and distribute their data, those data will be added to the database and listed in the clearinghouse.

DATA MAINTENANCE, MANAGEMENT, AND DISTRIBUTION

Data maintenance, management, and distribution will primarily use the distributed clearing house model. Modifications will be made to ensure data availability for organizations that do not yet have online access, but the system will be designed to encourage migration to online operation. The SAST clearinghouse will serve as a prototype for the Federal Geographic Data Committee (FGDC) and will help promote the NSDI as part of the NII.

Data Maintenance

It is necessary to ensure that the data are kept current. An initial database was created by the SAST, and it is clear that many data sets within the database will continue to change. For instance, land use and land cover data should be updated periodically to provide information on land use changes that might be taking place due to the institution of policies. The levee data should be updated as levees are added, removed, modified, or repaired to ensure that a current data set is available for hydraulic modeling or for use during time of flood and post-flood damage repair. Periodic surveys of biologic species should be made to help monitor the health of the ecosystem and to evaluate changes in biodiversity. Likewise, currency must be maintained for many other data sets.

Data Management

The management of the data will be the responsibility of the Federal or non-Federal organization that has the logical responsibility for that particular data set. However, Federally approved exchange standards will be used wherever possible and data will be maintained so that they are consistent, compatible, and intercomparable. Examples of agencies that should manage specific data sets include USACE - levee data, NBS - biological data, USGS - stream gage data, and EPA - contaminants.

Data Distribution

All non-proprietary digital data will be available for release to Federal agencies and the public at large. Given the magnitude of the SAST data-collection effort and the spirit in which it was conceived, it is imperative that the results be distributed as widely as possible.

Follow on efforts will include management and distribution activities, including a clearing house and online accessibility from the Internet for some data sets. Among the approaches being investigated are hypertext application written with the Mosaic software and a Wide Area Information Service (WAIS) application. The Mosaic hypertext application can provide a window-based browser environment for interested persons to read or download documents or graphics. In this way, SAST documents would connect with the World Wide Web, a global scientific information service (Krol, 1994). In the WAIS environment, choices can be made using spatial searches.

Primary access to the SAST database will be through the Internet using Mosaic and World-Wide Web services. This will allow for almost immediate access to the most current versions of the individual data layers and associated documentation such as spatial metadata and related publications. For data that are to be maintained at other sites, a clearinghouse function will be provided. For users who do not have Internet access, CD-ROM diskettes and other media (for example, 9 track and 8mm tape) containing selected data sets will be made available, depending on resources. However, the most current data sets will generally be available online.

Initial release of some data is as beta test versions to selected users. The feedback from these users will aid in improving the quality of the data sets. Once selected data sets are available for release, some will be made available on CD-ROM. However, due to the size of the database, releasing the entire database on CD-ROM is impractical.

For some high density data sets, such as satellite data that will be maintained near-line or offline, distribution will be by tape because of the large data volume.

The clearinghouse activity will consist of cooperating Federal and non-Federal organizations maintaining and distributing the data for which they have logical responsibility.

Access to Data

The primary distribution mechanism for SAST data will use Internet and World-Wide-Web capabilities. Mosaic software will be used as the browse method. Mosaic users can access SAST data from the following URL:

http://edcwww.cr.usgs.gov/sast-home.html

For users who do not have mosaic, but have access to Internet, the necessary mosaic software (freely distributed for Unix, PC, and Macintosh platforms) can be acquired using anonymous FTP access to:

ftp.ncsa.uiuc.edu

A limited number of data sets will be available initially. As data sets are quality assured and documented, they will be made available through the Internet.

Section III

THE NATURAL SYSTEM

The mainstem physical river-floodplain systems are the pathways through which surface-water is transferred out of the river basin. Water enters the streams and floodplains via surface-water runoff and groundwater flow from the upland areas of the river basin. Thus, it is imperative to understand the hydrologic processes of the upland part of the basin as well as the river-floodplains to address issues of flooding and structural and nonstructural flood-control measures. While precipitation drives the flood process, the terrestrial physical and biological systems are controlling factors in the concentration, distribution, and dispersal of rain water and snowmelt.

Section III of this report describes the hydrology and climatology of the river basin, the physiography of the uplands, and the geomorphology and ecology of the floodplain. This is the logical progression from the source of the water, to the major conditions controlling water flow to the river channels and floodplains, to the physical dynamics of the floodplains and the status of the floodplain ecosystem.

Chapter 3

HYDROLOGY

Floods in the Upper Mississippi River Basin result from rainfall and, to a lesser degree, snowmelt. In comparison with riverine flood flows, rainfall is widely dispersed geographically and very highly concentrated in time. As the storm water moves toward the outlet of the drainage basin, it becomes increasingly concentrated. This change in the spatio-temporal distribution is accompanied and made possible by temporary storage of the water as it moves across the surface and through the subsurface of the drainage basin. This chapter describes and explains the major processes that affect or are affected by the movement of storm water through the drainage basin, explains the importance of storage in these processes, and illustrates these processes by discussion of the 1993 flood.

HYDROLOGIC CYCLE

The hydrologic cycle (illustrated in figure 3.1) is the continual cycling of water from the atmosphere as precipitation, into the soil and groundwater system as infiltration and percolation, over the land surface as runoff, and back into the atmosphere as evaporation and evapotranspiration. The flow of water through the hydrologic cycle is described by a water budget or hydrologic storage equation. This is simply an expression of the principle of conservation of matter: water is not created or destroyed but simply changes location or form. The water budget states that the difference between the sum of all inflows and the sum of all outflows at any location in the hydrologic cycle is the change in the quantity of water stored.

During storm-runoff periods, the major inflow to a drainage basin is precipitation and the major outflow is streamflow. Evaporation tends to be relatively minor during storm periods, but can be very important between storms. Groundwater flow is generally much slower than stream-channel flows, but is distributed over such large areas that the total flow rate can be important. The difference between the precipitation inflow rate and the stream-channel outflow rate is accommodated by an increase in the volume of water stored in the drainage basin. This water is stored in the stream channel (increased flow depth), on the floodplain and land surface, in surface depressions of all sizes from puddles to potholes and ponds, in alluvial deposits in the stream banks, and in the soil. Groundwater flows are important because they are the means by which water moves into and out of storage in the subsurface. On the one hand, the slow velocity of groundwater flow causes stored water to be released to the stream only slowly, contributing to flood flow reduction. On the other hand, the same low flow velocities limit the rate at which water can move from the surface into storage in the subsurface, and thus limit the effectiveness of subsurface storage for flood flow reduction.

For discussions of flood flow reduction, the critical word in the statement of the water budget is "change." For a given inflow (precipitation), the outflow (streamflow) can be reduced only by changing (increasing) the volume of water stored in the basin. If the available storage capacity of the basin is completely or nearly filled, then there can be little or no reduction of the outflow relative to the inflow. Similarly, if the rate at which water can flow into storage is much smaller than the inflow rate (as happens frequently when the rainfall rate exceeds the infiltration capacity of the soil), then the change in storage will be inconsequential, the available storage capacity will be ineffective, and there will be little reduction of the outflow rate relative to the inflow.

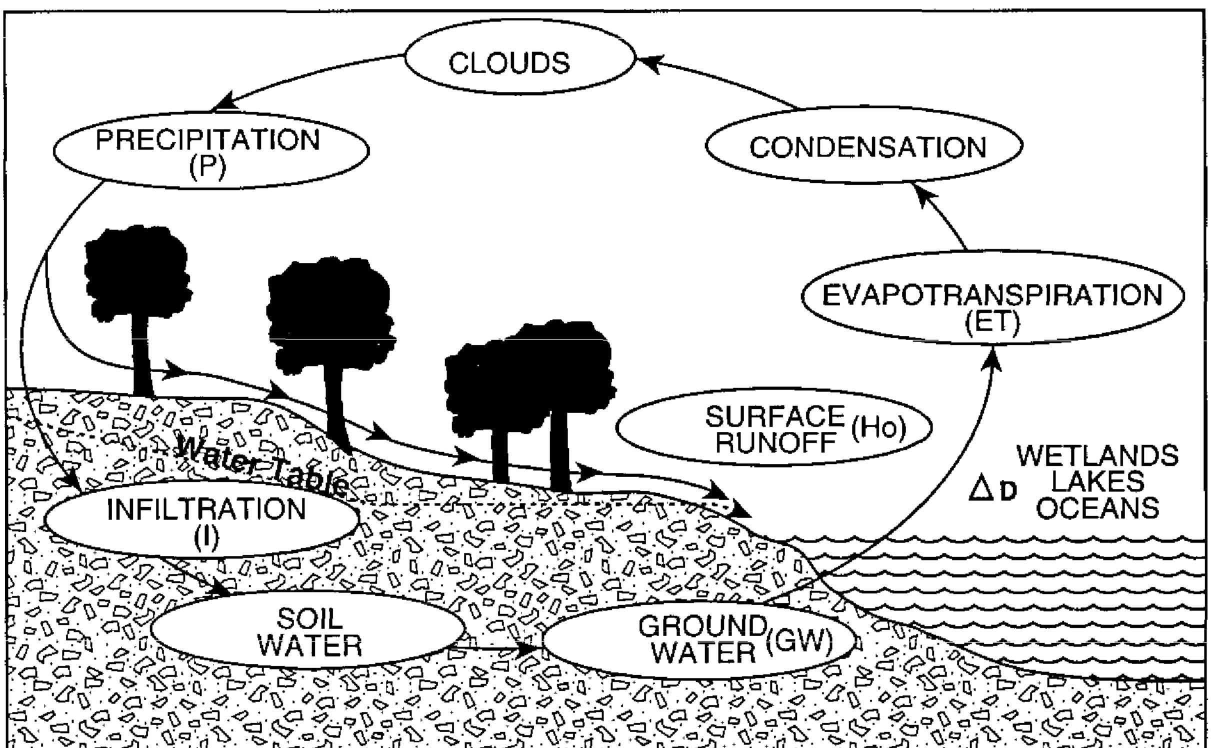


Figure 3.1 The hydrologic cycle in its broadest form. ΔD = Storage

SURFACE WATER

Figure 3.2 contrasts the two major hydrologic environments of concern in the study area: closed landscapes and open landscapes. The closed landscape, shown on the left of the figure, is characterized by large quantities of surface storage, which is largely absent in the open landscape. It can be seen that the storage volume in the closed system must be filled to the level of the lowest outlet before the closed basin begins to contribute to flows in a river or stream outside the basin. Local flooding can occur in the local basin as water levels rise, even though the basin is not contributing to flooding outside of the basin. If the high-elevation area separating the closed basin from the stream is overtopped by a flood event or breached by a drainage channel, the closed basin becomes part of an open system and contributes rapidly to flows in downstream channels. The storage, evaporation, and groundwater recharge components of the hydrologic cycle are then normally reduced relative to a closed system.

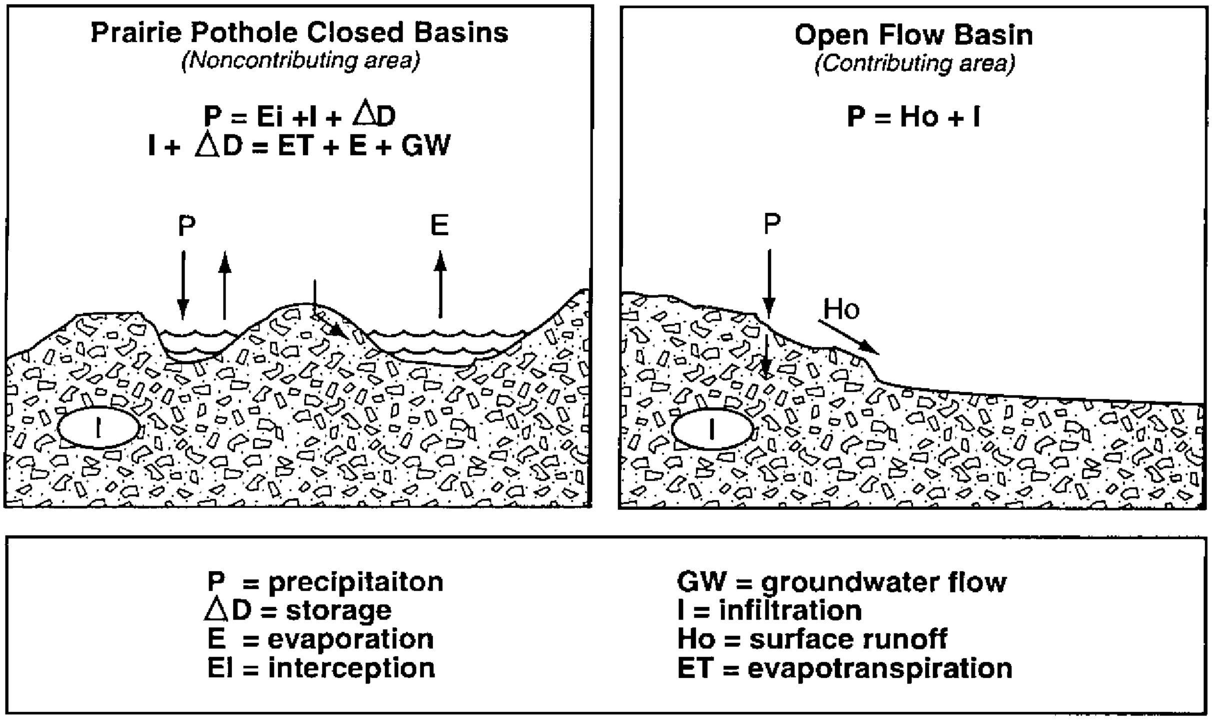


Figure 3.2 Closed landscape contrasted with an open flow system.

In many past studies, various aspects of the hydrologic cycle have been ignored. In particular, the impact of storage in closed landscape areas, in soil, and in groundwater often has not been appreciated (Richardson, personal commun., 1994). The storage component in closed landscapes is of major importance for reduction of local flood runoff. Flooding can occur within large or small closed basins as well as in open basins. As the basins fill from excess rainfall and expand into surrounding areas, flooding may occur in the surrounding areas, as in the case of Devil's Lake Basin in North Dakota (Wiche and others, 1990).

GROUNDWATER

Groundwater conditions in the alluvial floodplains of the SAST study area are directly related to surface water conditions. The porous alluvial sediments underlying the floodplain and main channel provide substantial storage capacity for water and allow the stored groundwater to communicate freely with the water in the river channel. When flow rates and stages are low in the main channel, water drains out of the alluvium and sustains the flow in the river. When river flows and stages are higher than the groundwater level in the alluvium, water flows out of the river channel into the alluvium and the groundwater level rises. The diversion of water out of the channel provides some attenuation of the flood peak; however, groundwater flow velocities and discharge rates are low relative to surface water flows, and the attenuation is normally small for large flood events.

In addition, the rising groundwater levels may have significant effects on the floodplain. Alluvial river channels commonly form natural levees when sediment is deposited by flood water as it moves into slower moving areas on the floodplain. When the river is confined by natural or artificial levees and remains for sufficient time at a stage higher than the land surface in the floodplain behind the levee, the groundwater level eventually rises to the surface and inundates the floodplain even though the levee is not overtopped or breached. Rainfall directly on the floodplain and lateral runoff to the floodplain from adjacent upland areas also contribute to this problem, which is known as interior flooding.

Groundwater conditions in upland areas also are related to rainfall-runoff conditions that cause flooding in rivers and valleys. Rainfall that exceeds the infiltration capacity of the soil will either run off the land surface or accumulate (pond) in local depressions until removed by infiltration or evaporation. Water that does infiltrate may evaporate, may be transpired by plants (combination known as evapotranspiration), or may migrate as groundwater and eventually re-emerge at the foot of hillslopes or in the alluvial valleys. It may also be stored in a regional aquifer, or may emerge hundreds of miles away. Soil materials in the upland areas commonly are less permeable than alluvial valley fill, so groundwater velocities in the uplands tend to be lower than velocities in the floodplains. The low velocities and the distance between the uplands and the river channel imply that groundwater flow from the uplands has relatively little effect on river flood peak flows. However, upland areas are much larger than the floodplain area, so the total volume of groundwater flow from the uplands over time is important in replenishing the alluvial valley aquifers and maintaining flow in the rivers between rains.

Groundwater quality and surface water quality also are directly interrelated. The quality of the groundwater is determined by the quality of the precipitation and infiltrating water, by the quality of any river water that flows into the alluvial aquifer, by the characteristics of the soil materials through which the groundwater moves, and by the rates of flow and transport in the groundwater and surface water systems. The quality of the river water in turn is affected by the quality of the groundwater that drains back into the river during low water. Depending on local conditions, either the surface water or the groundwater may be of better quality.

Primary groundwater quality concerns relative to flooding are the effects of non-point source contaminants as related to land use and the effects of point source contaminants that may be released during floods either by inundation of storage facilities or by spills and leaks.

The interrelationship of the surface and groundwater makes the consideration of groundwater effects important in floodplain management. Additional information regarding how to quantify the range of groundwater flow and transport rates into receiving streams under high and low flow conditions is needed. This information could be used to determine the relative importance of groundwater contributions during flood flows and to determine whether or not the groundwater needs to be further considered in development of flood policy. However, development of this information would require hydrogeologic and geochemical model studies as well as enhancement and maintenance of ongoing monitoring programs for groundwater levels and quality. The information is also needed to determine the effects of management practices that increase infiltration of water into the soil since these practices may cause increased flow to the groundwater system.

THE 1993 FLOOD

A persistent series of heavy summer rain storms, following an unusually wet period from the previous summer and fall (1992) through the spring of 1993, caused severe flooding in the SAST detailed study area in the summer of 1993. Meteorological and hydrologic characteristics of the floods have been described in reports by the National Weather Service Climate Analysis Center (1993a,b), Wahl and others (1993)(precipitation), Parrett and others (1993) (flood peak discharges), and Perry (1994) (effects of reservoirs). The following discussions of the 1993 flood are based on these references.

Precipitation

The extent and duration of the flooding in the Upper Mississippi River Basin primarily was due to excessive precipitation in the region from January through August 1993. Most weather stations in the Upper Mississippi River Basin reported normal to slightly greater than normal precipitation during the period January to March 1993, but the potential for widespread flooding was not a major concern at that time.

Precipitation during April and May was variable throughout the region. Nearly all stations had normal or above normal precipitation during these months with many stations in Iowa and Missouri reporting twice the normal April to May precipitation. By the end of May, soil moisture throughout most of the region was excessive, reservoirs were reaching capacity, and river stages were above normal.

During June through August, the weather pattern over the Upper Mississippi River Basin was dominated by a low-pressure system over the western United States and a corresponding high-pressure system over the southeastern United States. An eastward-flowing jetstream extended from central Colorado northeastward across Kansas to northern Wisconsin. This created a convergence zone between the warm, moist flow from the Gulf of Mexico and the cool dry air from Canada. This condition caused precipitation throughout the region to be substantially greater than normal; in many locations, precipitation amounts for July and August were greater than twice the normal amounts. A comparison of 1993 precipitation and normal precipitation for the study area is shown in figures 3.3a to 3.5 for the fall and winter preceding the flood and for the summer of 1993. Figures 3.3a and 3.3b show precipitation amounts for the two time periods, and figures 3.4a and 3.4b show percentages of normal for the same periods. Some areas in the basin experienced rainfall in excess of the 200-year recurrence interval for the 2, 3, 4, and 12 month periods (Kunkel and others, 1994). By the end of June, most of the soils throughout the region were saturated and the rainfall that occurred in July produced excessive runoff and severe flooding throughout the region (Wahl and others, 1993).

The Effect of Storm Timing

Flooding on the main stems of the Missouri and Mississippi Rivers was aggravated by the timing of several rainstorms in late June through July. During June 17-18, 2 to 7 inches of rain fell in southern Minnesota and northern Iowa, causing near-record flooding on the Minnesota and Mississippi Rivers in Minnesota. The flood crest from this storm reached Clinton, Iowa, on July 5, 1993. Two rainstorms in early July caused record peaks on the Iowa, Skunk, and Des Moines Rivers in Iowa, and significant flooding throughout the region. The flood crests from these rivers entered the Mississippi River at about the same time that the flood peak from the June rainstorm reached the Mississippi River at Keokuk. The coincident timing of the flood peaks from these tributary streams increased the peak discharge on the Mississippi River downstream from Davenport, Iowa. The discharge from these combined floodwaters reached St. Louis, Missouri, on July 20, 1993.

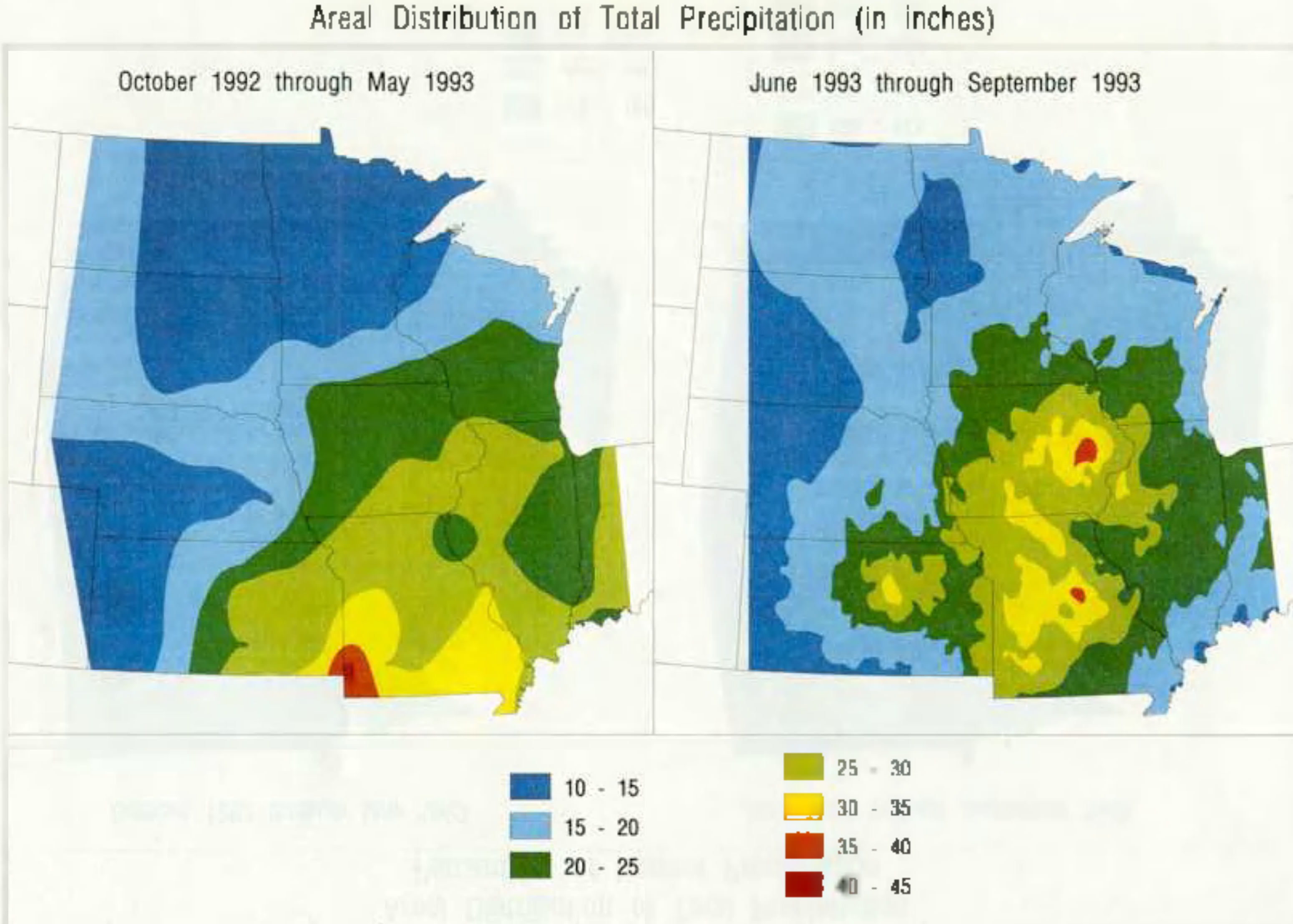

Areal Distribution of Total Precipitation (in inches)
October 1992 through May 1993
June 1993 through September 1993
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40
40 - 45

Figure 3.3 a & b

Areal Distribution of Total Precipitation
Percentage of Normal Precipitation

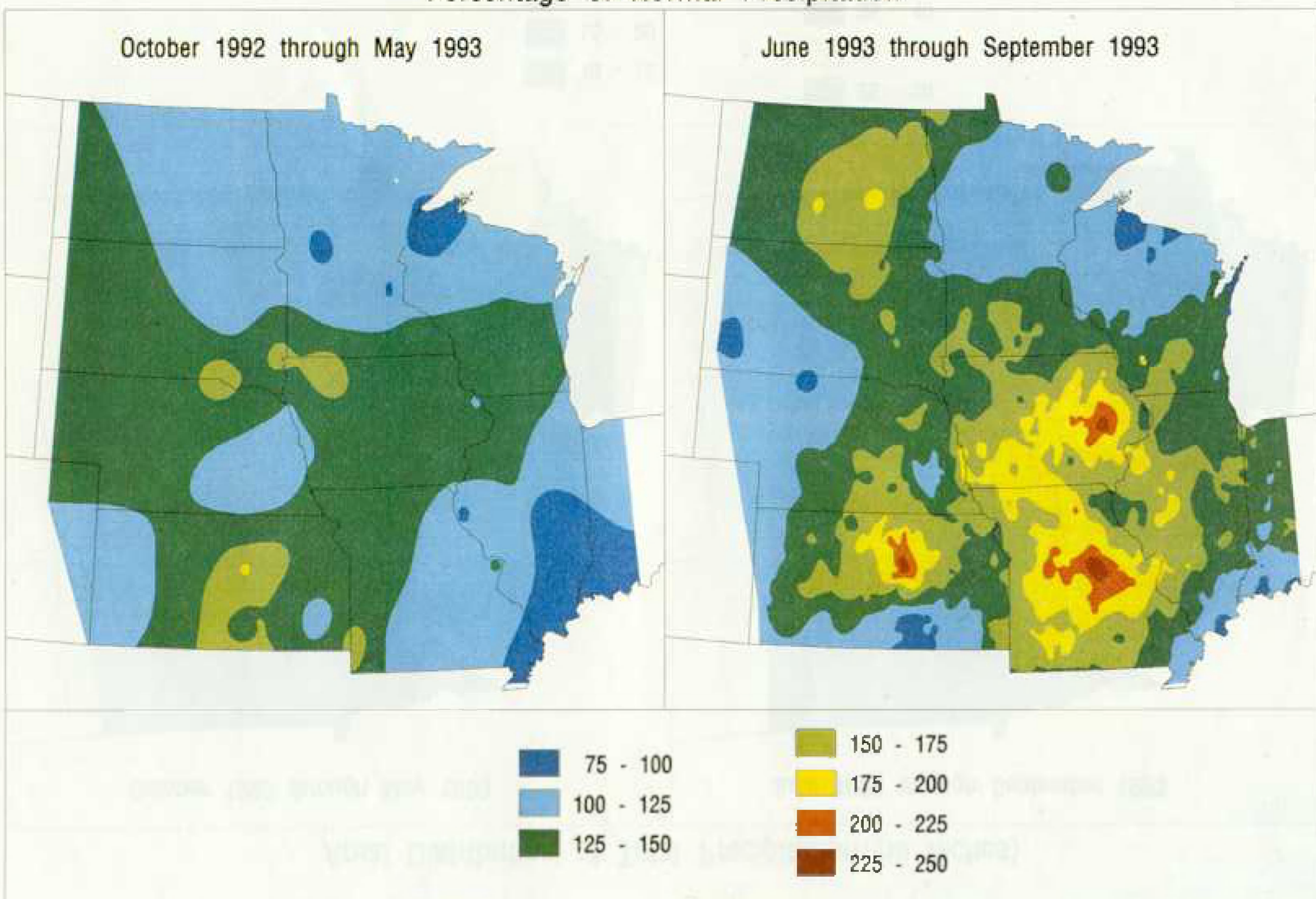


Figure 3.4 a & b

Rainstorms on July 15-16 and July 22-24 in the Dakotas, Nebraska, western Iowa, Kansas, and Missouri caused record flooding on the lower Missouri River. The flood crest from these storms reached the Mississippi River at St. Louis on August 1 and caused a second and greater peak discharge. This flood crest reached Thebes, Illinois, on August 7.

Flooding on the Mississippi River downstream from the confluence of the Ohio River did not cause severe problems. Discharge on the Ohio River basin was reduced by the generally dry conditions throughout the basin. As a result, the large channel capacity of the Mississippi River below the confluence of the Ohio River was able to convey the combined discharge without serious flood problems (Parrett and others, 1993).

Peak Discharges and Volumes

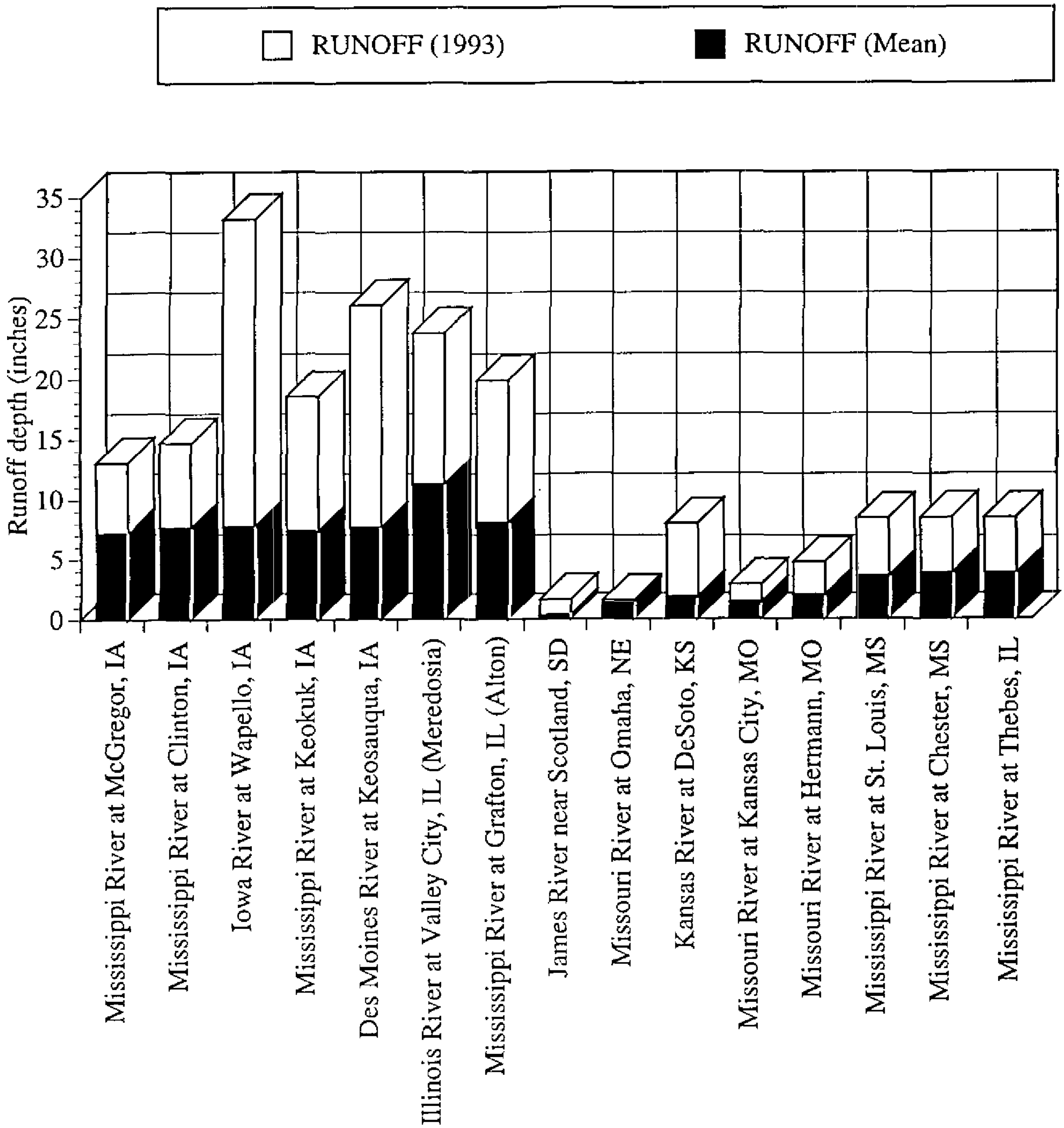
Parrett and others (1993) provide flood data for 154 streamflow gaging stations that were identified during the flood as having experienced flood peaks that exceeded the 10-year recurrence interval discharge (10-percent annual exceedance probability). At 45 of these stations, the recurrence intervals exceeded 100 years (annual exceedance probability less than 1 percent), and at 56 stations the discharges exceeded either the previous maximum known discharge or the previous maximum regulated discharge. About half of the stations, mainly on the smaller basins, had peak discharge recurrence intervals in the range of 10-50 years. The floods with higher recurrence intervals generally were on the mainstem Missouri and Mississippi Rivers and on a few basins in Iowa.

The 1993 floods were notable for their areal extent, duration, and volume of runoff. During the period April 1 to September 30, 1993, the Mississippi River remained above flood stage for 144 days at St. Louis and for 152 days at Thebes, and the Missouri River exceeded flood stage at Hermann for 116 days; 3-day mean flows exceeded the 100-year recurrence interval level for 3-day mean flows of at least 22 streamflow gaging stations, and 120-day mean flows exceeded the 100-year level of at least 43 stations; April-September mean flows were greater than twice the historical mean flows for the period of at least 53 stations (R. Southard, USGS, written commun., 1993). The annual mean flows and runoff depths for 1993 are compared with historical mean flows and runoff depths at selected stations in table 3.1 and figure 3.5.

The areal extent, duration, and timing of the flooding ensured that the flood waves from many tributaries would reinforce each other when they reached the mainstem rivers. Thus, the mainstem flows tended to be more extreme in terms of recurrence interval or exceedance probability than the individual tributary floods.

Table 3.1 Comparison of water year 1993 mean discharge and runoff with mean annual discharge and runoff for period of record (USGS Annual Water Data Reports).

Station Name	Drainage Area sq mi	WY 1993 Mean Flow cfs	WY 1993 Runoff Depth inches	Period of record through WY 1992 Mean Flow cfs	Period of record through WY 1992 Runoff Depth inches
Mississippi River at McGregor, Ia.	67500	64720	13.02	35520	7.15
Mississippi River at Clinton, Ia.	86500	92300	14.64	48000	7.62
Iowa River at Wapello, Ia.	12499	30550	33.20	7120	7.74
Mississippi River at Keokuk, Ia.	119000	162500	18.55	64520	7.36
Des Moines River at Keosauqua, Ia.	14038	26920	26.05	7909	7.65
Illinois River at Valley City. Ill. (Meredosia)	26742	46810	23.77	22110	11.23
Mississippi River at Grafton, Ill. (Alton)	171300	250700	19.87	101500	8.04
James River near Scotland, S.D.	16505	1959	1.61	414	0.34
Missouri River at Omaha, Neb.	322800	36410	1.53	32000	1.35
Kansas River at DeSoto, Kans.	52200	30570	7.96	7060	1.84
Missouri River at Kansas City, Mo.	458200	102100	2.86	50050	1.40
Missouri River at Hermann, Mo.	524200	181800	4.71	76780	1.99
Mississippi River at St.Louis, Mo.	697000	429700	8.37	181900	3.55
Mississippi River at Chester, Ill.	708600	441700	8.46	198500	3.81
Mississippi River at Thebes, Ill.	713200	446000	8.49	198000	3.77



Fgure 3.5. Comparison of Water Year 1993 and mean annual runoff, upper Mississippi and lower Missouri Rivers

Effects of Reservoirs

The effects of flood control reservoirs on flood peaks varied significantly between the Missouri and Mississippi River basins. Flow volumes on the Mississippi River tributaries on the Iowa and Des Moines River basins (R. Southard, USGS, written commun., 1993) were as great as ten times the reservoir volumes. Consequently, during the flooding in July, the storage capacity of the reservoirs was exceeded. Nonetheless, flood damage was reduced through the operation of these reservoirs. For example, storage operations at Saylorville reservoir on the Des Moines River upstream from Des Moines reduced the July maximum daily outflow by about 10,500 cfs, or 20 percent of the computed unregulated outflow; the corresponding reduction in stage is about 2 feet. Although the flood peaks on these tributaries were reduced, the overall effect of these reservoirs on the flood crest on the main stem of the Mississippi River was minimal.

The flood control reservoirs on the Missouri River basin had a significant effect on reducing flood discharges on the lower Missouri main channel and on the Mississippi River downstream from the confluence of the Missouri River. Runoff from the upper Missouri River basin was contained by the dam system upstream from Gavins Point Dam. This reduced the flow on the lower Missouri River by about 80,000 cfs. Reservoirs on the Kansas River reduced the flood crest entering the Missouri River by about 85,000 cfs, or 34 percent of the computed unregulated flow. The combined effect of flood control reservoirs in the Missouri River reduced the average discharge on the Missouri River at Hermann (and at the confluence of the Mississippi River) for the month of July by about 211,000 cfs (Perry, 1993), which is about 36 percent of what the unregulated July 1993 discharge would have been at Hermann. The corresponding reduction in Mississippi River peak stage at St. Louis is about 5 feet. Although Missouri River reservoir levels were unusually low at the beginning of the flooding in 1993 due to drought in the preceding years, similar peak flow reductions would have been obtained if the reservoir system had started 1993 at normal storage levels. However, more of the flood-control storage zone of the reservoirs would have been filled than actually was filled in 1993, and the releases required to evacuate the flood-control zone in the autumn would have been significantly higher than the actual 1993 autumn releases (D. Sveum, USACE, oral commun., June 13, 1994).

HYDROLOGIC ISSUES AND RESEARCH NEEDS

Effective analysis of flood management options requires a wide range of critical hydrologic information, including precipitation-runoff relations, magnitude and frequency of precipitation and flood events, and effects of land use and land management practices on flood response. Analysis and research that could provide useful information include the following activities.

Regional hydrologic modeling of rainfall-runoff, erosion, and transport processes -- Simple water-balance analyses, comparing rainfall, streamflow, and reservoir data for 1993 and selected historical floods, would provide valuable information on water storage capacity of drainage basins. Calibrations of rainfall-runoff models for various representative basins would provide information on flood response characteristics of basins in different terrain and landscape types. Models of groundwater-surface water interactions and transport of sediment and other water quality constituents also would be needed to address water quality and subsurface-flow aspects of flooding. Correlations of flood response characteristics with drainage basin physiographic characteristics would be needed for extrapolating results of detailed model studies to the regional scale needed for policy analysis. Identification of weather patterns associated with extreme flooding would provide a physical basis for improved estimation of flood magnitude-frequency relations.

Recommendation 3.1: Federal, state, and local agencies should cooperate in programs to a) develop hydrologic and hydraulic models to define flood-response characteristics, including groundwater flow and transport of water-quality constituents, of river-floodplains and upland watersheds in the Upper Mississippi River Basin;
b) determine drainage-basin physiographic, land-use, and land-management characteristics affecting flood response in the Upper Mississippi River Basin, with a view toward regional-scale assessment of effects of improved land-use and land-management practices on flood response, and
c) extend and enhance existing observation networks as needed to obtain surface-water, groundwater, water-quality, and meteorological data required for development and application of hydrologic and hydraulic models.

Regional analysis of statistical frequency and magnitude of flood occurrence -- Reanalysis of historical flood records (and paleo-hydrologic evidence of prehistorical flooding) is needed to update estimates of flood magnitude-frequency relations. Analysis of the effects of the 1993 flood on the estimates is needed for appraisal of statistical sampling errors. Development of regional relations between drainage-basin characteristics and flood-magnitude-frequency relations is needed to permit flood estimation at ungaged sites; it would also help to improve the accuracy of estimates at gaged sites. As part of this effort, the adequacy of the stream gaging network for defining regional flood statistics could be evaluated and necessary improvements identified. Statistical analysis of weather patterns associated with extreme flooding could provide a basis for assessing effects of potential climate changes on flood frequency and magnitude. Finally, improved flood magnitude-frequency relations could be used to update and improve flood insurance rate maps and floodplain delineations.

Recommendation 3.2: Federal, state, and local agencies should cooperate in programs to
a) develop up-to-date coordinated estimates of statistical flood frequency-magnitude relations, including flood-elevation profiles and flood-risk delineation maps, at gaged and ungaged sites, for use in floodplain planning, management, and regulation in the Upper Mississippi River Basin;
b) review and evaluate existing and proposed methodologies for statistical flood frequency estimation, at both gaged and ungaged sites, and identify or develop improved methodologies, if necessary, and
c) review and evaluate the adequacy of the existing streamflow-gaging network for defining flood risk in the Upper Mississippi River Basin, and extend and enhance the network, if necessary.

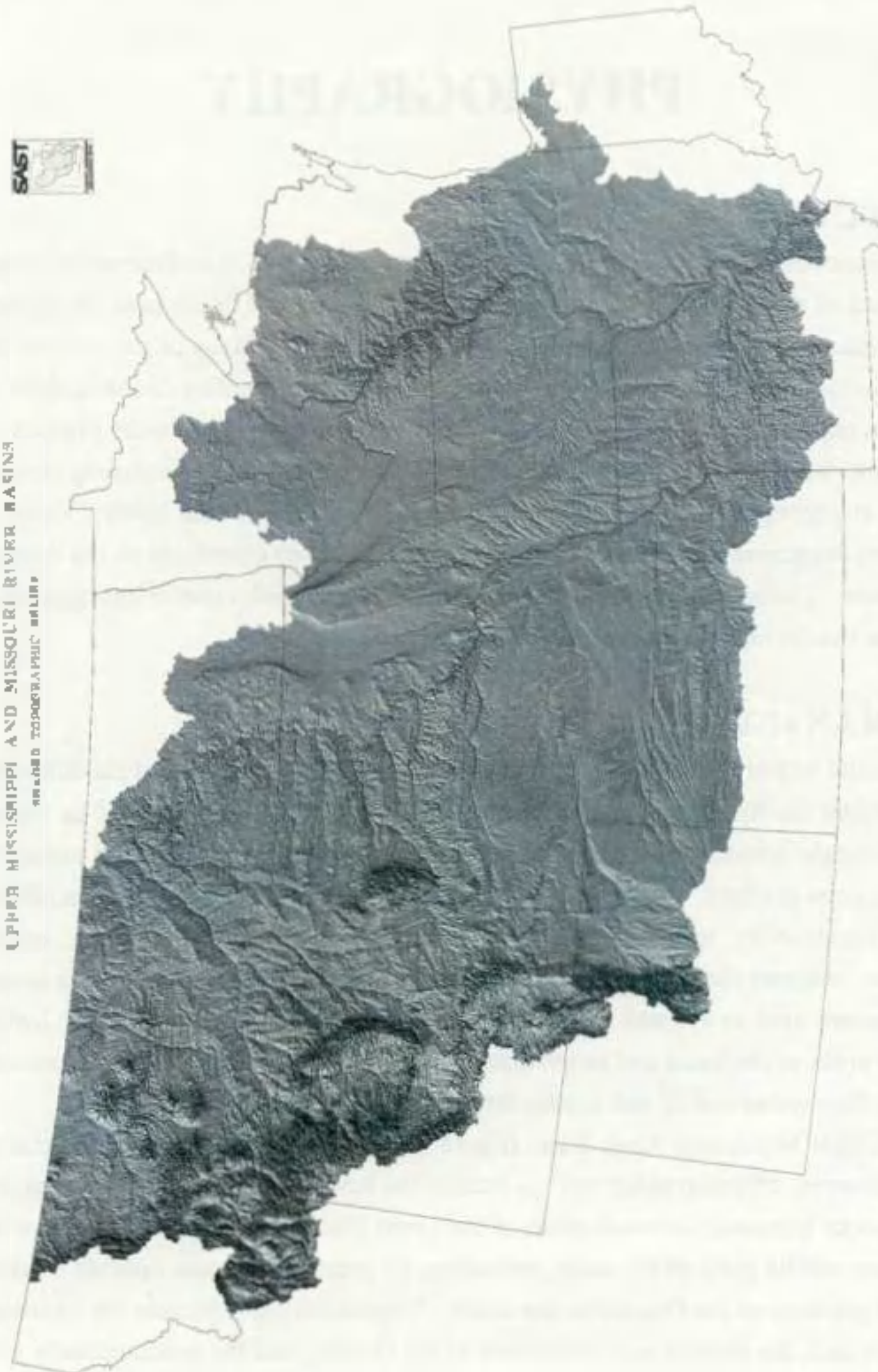

UPPER MISSISSIPPI AND MISSOURI RIVER BASINS
SHADED TOPOGRAPHIC RELIEF
SAST

Figure 4.1

Chapter 4

PHYSIOGRAPHY

INTRODUCTION

The mainstem river systems are the pathways through which surface-water ultimately is transferred out of the river basin. Water enters in the streams and floodplains via surface-water runoff and groundwater flow from the upland areas. The physiography of the uplands is a controlling factor in the flow of water to the floodplains. The objective of the analysis and description in this chapter is to show the interrelationships among the primary physical characteristics: landscape morphology and terrain heterogeneity, soils (including parent material, distribution, and topography), drainage density, wetland extent and land cover. These characteristics determine storage or runoff potential. Thus they contribute to the dynamics of flood processes. Understanding and classifying the terrain provides useful information to assist in extending the results of local analyses or evaluating such extensions.

TERRAIN ANALYSIS

An initial activity of the river-basin analysis was to develop a terrain classification system that characterizes the hydrologic response of different parts of the basin as well as the basin as a whole. Hydrologic response is affected by many factors including land use and management practices; hillslope gradient, aspect, and variance; drainage patterns and density; surficial deposits, soil texture, permeability, water storage capacity, soil hydrologic groups; and land cover. The terrain classes integrate these factors to characterize the hydrologic response of an area. These terrain classes are used as a means to extend limited research and model results on hydrology to other similar areas of the basin and to evaluate alternative land management and structural means to control surface water runoff and stream flow.

The Upper Mississippi River Basin (figure 4.1) is physiographically, ecologically, and climatically diverse. Physiographic regions include the Rocky Mountains on the western border, the rolling Rocky Mountain outwash areas of the Great Plains, the relatively level glaciated plains in the northern middle parts of the basin, the rolling till prairies and loess uplands on the east, and the dissected plateaus of the Ozarks on the south. Vegetation types include the intensively managed corn belt, the pasture and woodlands of the Ozarks, and the predominantly grassland or wheat areas in the Great Plains.

Preliminary geographic analysis shows that this region can be divided into as many as 70 terrains on the basis of slope variance and aspect (figure 4.2). Further analysis is needed to determine if each of these 70 terrains is unique with respect to hydrologic response. Other land resource maps (Soil Conservation Service, 1981, Agricultural Handbook 296) subdivide the basin into about 44 Major Land Resource Areas (MLRA's). The MLRA's are separated by differences in soils, topography, climate, water resources, potential natural vegetation, and land use.

Recommendation 4.1: Develop a regionalization scheme (based on existing or new data, whichever are appropriate), to prepare hydrologic response units (HRU). These HRU's are used for developing broad scale hydrologic models and for evaluating the effectiveness of different potential nonstructural actions in uplands for reducing flooding.

The State Soil Geographic Database (STATSGO) of the Soil Conservation Service is an inventory of soil resources of the United States at a scale of 1:250,000. Map units in STATSGO are sets of polygons that have similar composition of soil components. Each polygon may have up to 21 different soil components. Slope is one of the attributes for each component. The distribution of slopes within each map unit in STATSGO was analyzed in terms of 5-percent slope intervals from 0 to 70 percent with additional categories for slopes greater than 70 percent, and for water. The distribution was represented as a set of 16 proportions for each map unit. A multidimensional distance between the map units was computed, and a clustering algorithm was used to group the map units into a set of 9 groups. The frequency distributions of slopes within the groups are shown as histograms in figure 4.3. These slope groups are plotted on a regional map to show the areal distribution of slope groups in the basin (figure 4.4). The colors in figure 4.4 depict slope groups sa1 to sa9. Group sa9 is water. Slope groups range from sa1 which has the flattest slope gradients, to sa8 which has the steepest gradients.

The mauve color shows the nearly level closed-drainage late-Wisconsinan glacial terrain of central Iowa, Minnesota, east central Illinois, and the Dakotas. The linear blue areas within the mauve in northwestern Iowa and southwestern Minnesota correspond to glacial moraines. The area west and south of the Missouri River in North and South Dakota and Nebraska has a wider distribution of slopes corresponding to the rolling nature of this erosional, dissected, and nonglaciated area. The east-west color patterns in the western part of the basin demonstrate the general nature of slopes and the drainage east from the Rocky Mountains. The dissected sloping loess areas along the Missouri and Mississippi Rivers are predominantly in classes sa3 and sa6. This open-drainage terrain is characterized by blue stringers representing the many streams in the area. The dissected area of broad interfluves covered by loess deposits in southern Iowa and

Figure 4.2 Preliminary terrain divisions. Approximately 70 terrain divisions were identified by visually inspecting a map displaying slope variance (the second derivative of elevation). The elevation data used to produce this map were the Defense Mapping Agency's ETopo5.

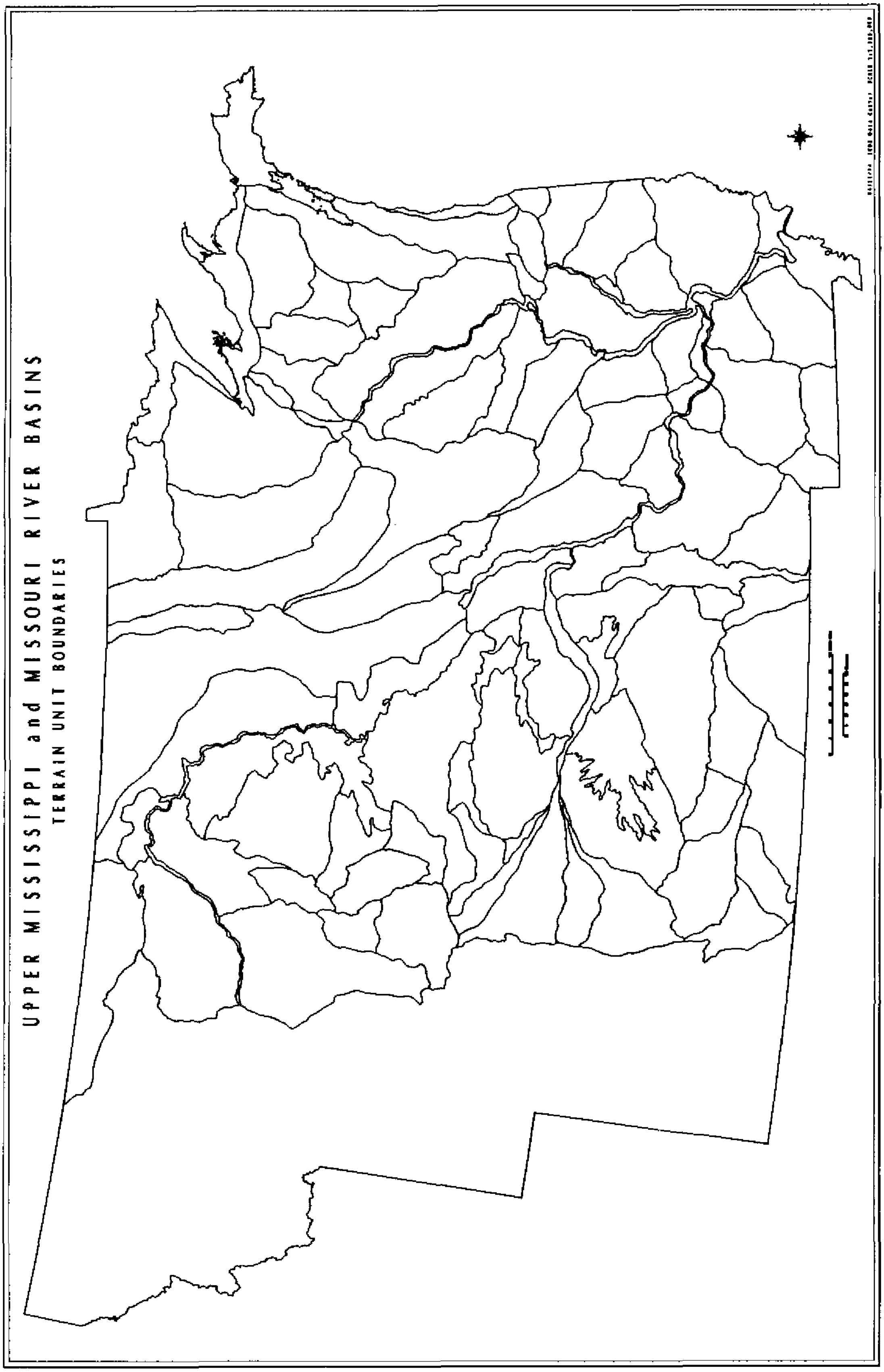
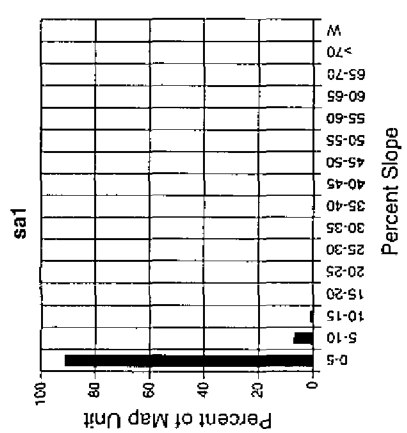
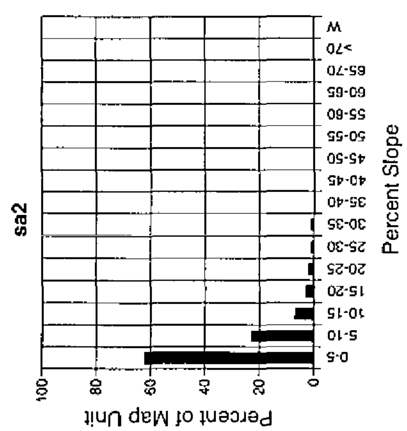
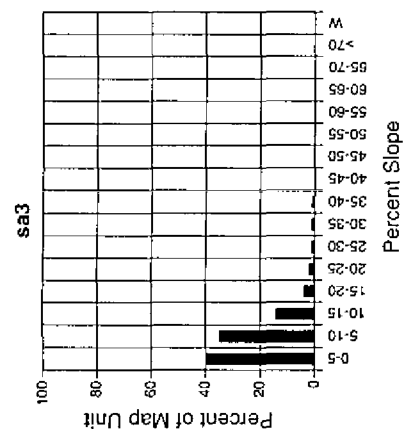
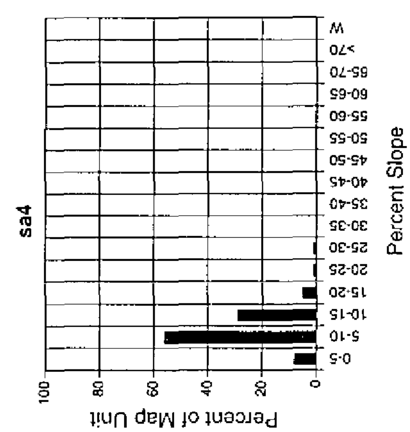

UPPER MISSISSIPPI and MISSOURI RIVER BASINS
TERRAIN UNIT BOUNDARIES

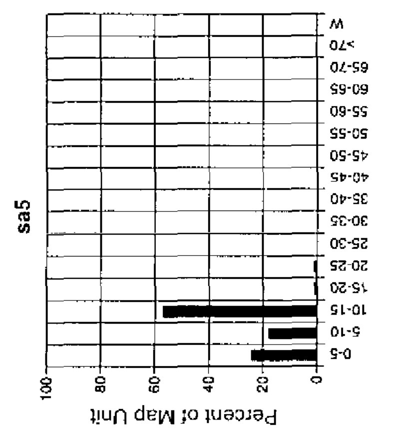
Figure 4.3 Soil slope groups formed by statistical clustering of the slope patterns within STATSGO map units. For each slope group, the area (in square meters, scientific notation) is shown for slope ranges of 5 percent slope. Code 0 represents 0 to 5 percent slope; code 5 represents 5 to 10 percent slopes, and so forth. Code >70 represents slopes greater than 70 percent. Code W represents non-soils, primarily water. The maps and statistics include all areas of the 13 state region, including areas outside the Upper Mississippi River Basin.

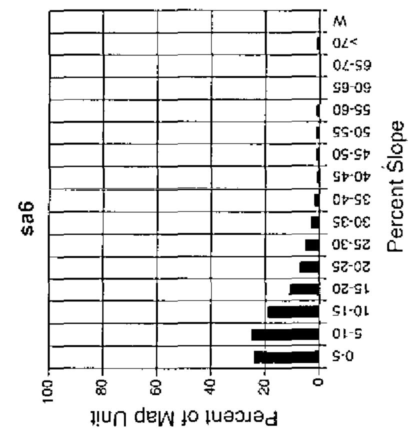

sa1
Percent of Map Unit
Percent Slope

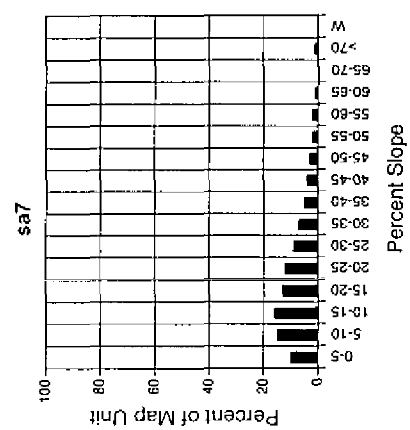

sa2
Percent of Map Unit
Percent Slope

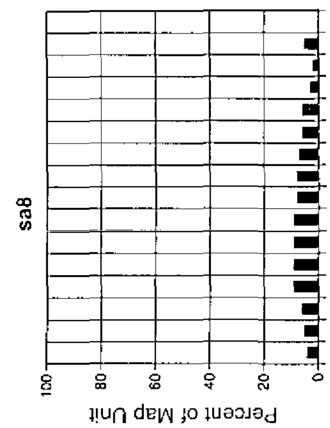

sa3
Percent of Map Unit
Percent Slope


sa4
Percent of Map Unit
Percent Slope


sa5
Percent of Map Unit
Percent Slope


sa6
Percent of Map Unit
Percent Slope


sa7
Percent of Map Unit
Percent Slope


sa8
Percent of Map Unit
Percent Slope

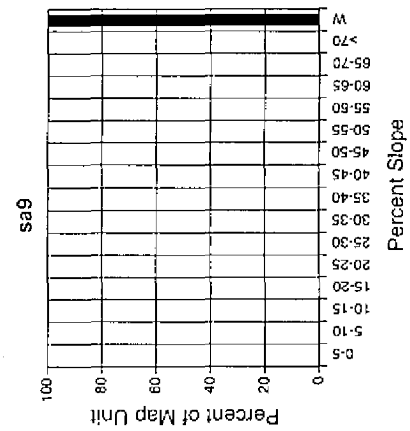
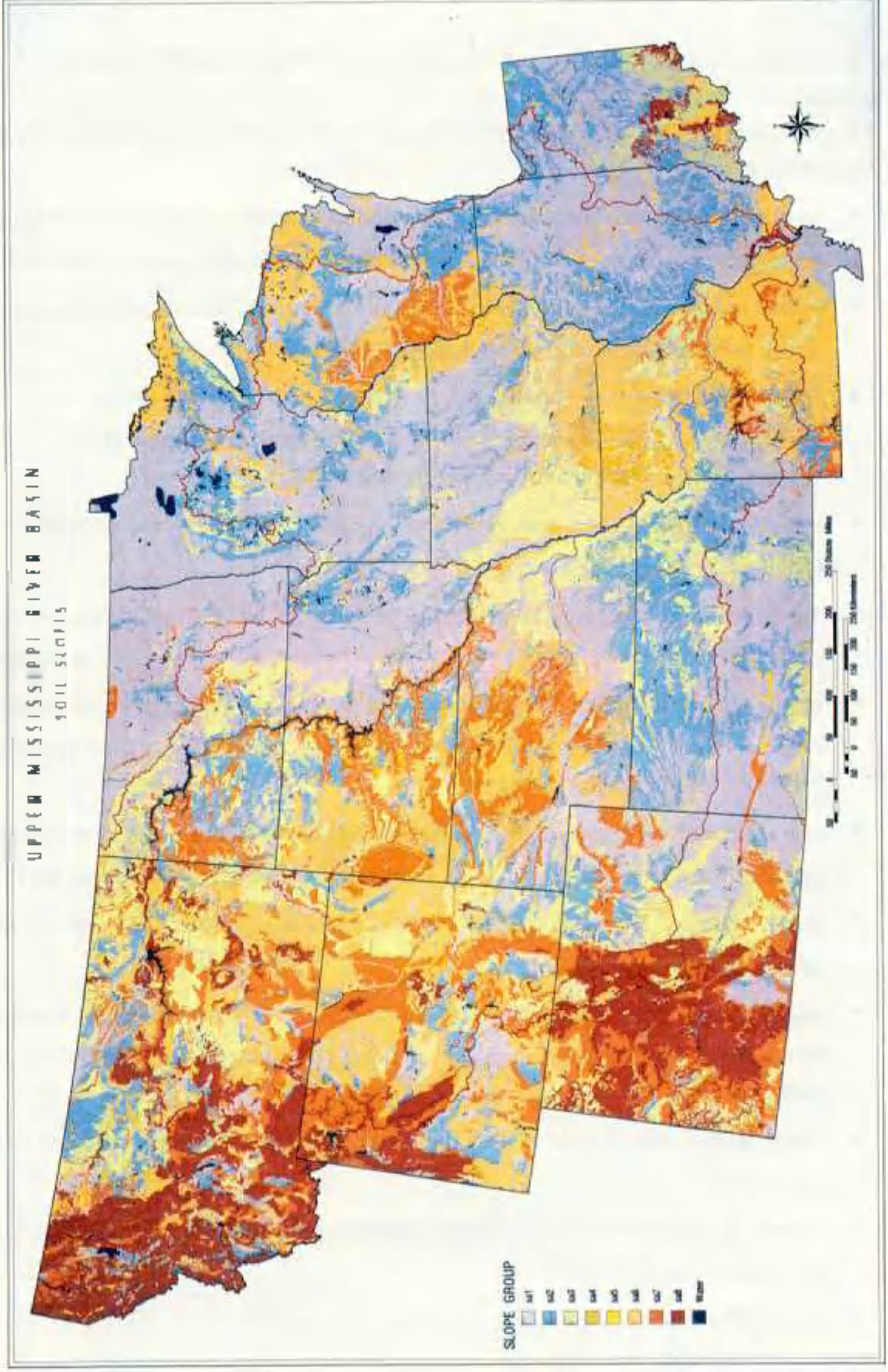

sa9
Percent of Map Unit
Percent Slope

Figure 4.4 Soil slopes are calculated from information in the STATSGO database of the U.S. Department of Agriculture, Soil Conservation Service. Map units in the 13 state study area were clustered according to similar distributions of slope. The slope groups shown here range from flat areas in sa1 to steep areas in sa8.


UPPER MISSISSIPPI RIVER BASIN
SOIL SLOPES
SLOPE GROUP

northern Missouri is uniquely separated as slope group sa4. This is roughly the Grand River drainage basin.

In very general terms, the entire Upper Mississippi River Basin is characterized by the following landscapes:

- level to gently rolling glaciated (prairie pothole) cropland of western North Dakota, northeastern Montana, and central South Dakota (dominantly slope group sa1)
- rolling soft shale cropland plains of southwestern North Dakota and northwestern South Dakota (dominantly slope groups sa2 and sa6)
- rolling high plains grass and wheatlands of Montana, eastern Wyoming and Colorado, and western South Dakota that are characterized by clay shale, siltstone, and soft sandstone (dominantly slope groups sa6 and sa7)
- rolling to steeply sloping sand dunes and grasslands of the Nebraska sand hills (dominantly slope groups sa6 and sa7)
- mostly loess-covered, level to gently rolling winter wheat and range region of the central Great Plains of Nebraska and Kansas (dominantly slope groups sa1 and sa2)
- rolling till prairies and deeply dissected loess uplands and till plains of the western part of the corn belt in eastern South Dakota, Nebraska, and Kansas, and western Iowa and Missouri (slope groups sa3 and sa6)
- nearly level till plains of southern Minnesota and central and eastern Iowa that include the largely artificially drained pothole region of the corn belt (slope group sa1)
- deeply dissected loess hills cropland along the Mississippi River (slope groups sa6 and sa7)
- nearly level to gently rolling clayey till plain of southern Iowa and northern Missouri that is about 50 percent cropland and 50 percent pasture and woodland (slope group sa4)
- nearly level clayey till plain of northern Illinois and western Indiana corn belt (slope group sa1)
- steeply sloping and dissected, wooded, northern part of the Ozark highlands(slope group sa6)
- Rocky Mountain foothills (slope groups sa7 and sa8).

SOILS IN THE BASIN

Soils are an important component in the physiography because they affect rates of water runoff to streams, absorption of water into the groundwater system, and vegetal land cover.

Surficial Materials and Soil Parent Materials

Surficial materials are consolidated earth materials which overlie bedrock and are the parent materials in which the surface and buried pedogenic soils have formed. Almost all of the soils in the Upper Mississippi River Basin have formed in parent materials that have been transported from their original source-rock areas. Figure 4.5 shows the distribution of surficial materials in the basin, the maximum extent of Pleistocene continental glaciation, and the extent of the last, late Wisconsinan-age glaciation. The late Wisconsinan glaciated area encompasses more than 50 percent of the basin, including the immature landscapes of the closed drainage or pothole region. In the upper Mississippi and lower Missouri River areas, these surficial materials are mostly comprised of wind-blown loess, glacial till, or glacial meltwater deposits, except for areas covered by weathered-rock and colluvial materials in the western parts of South and North Dakota, southwestern Wisconsin, and the extreme southern part of the basin. In the glaciated part of the area, surficial materials range in thickness from less than 3 feet to more than 400 feet (Soller, 1993); most of the surficial materials are calcareous or weakly calcareous.

The surficial materials of the region have been classified on the basis of inferred infiltration capacity through the surface soil profile and water storage capacity within the surficial material (Soller, 1993). Materials with relatively low infiltration/storage capacities include tills and weathered-rock materials. Clay loam and loamy tills (Gray and others, 1991; Hallberg and others, 1991; Soller, 1993; Whitfield and others, 1993) with thick, clayey soil profiles are present in the southern part of the glaciated area south of the limit of the late Wisconsinan (glaciation). Loamy tills and sandy loamy tills with moderately developed soil profiles underlie areas north of the late Wisconsinan glacial limit. These include areas of sandy loam, and sand and gravel moraine deposits in central Iowa (Hallberg and others, 1991), and large parts of Minnesota and northwestern Wisconsin (Goebel and others, 1983) that have closed drainage with high infiltration rates. The areas underlain by till also include large tracts underlain by surface peat and other permeable wetlands deposits in northern Minnesota. Clay and silt deposits, laid down on the bottoms of glacial lakes, are extensive in North and South Dakota. Clayey residuum and colluvium is present in southwestern Wisconsin (Hallberg and others, 1991; Lineback and others, 1983); silty to sandy clay or silt residual weathered-rock materials (Whitfield and others, 1993) underlie areas south and west of the maximum glacial limit. Materials with relatively high infiltration/storage capacities include coarse-grained, stratified glacial meltwater deposits that

Figure 4.5 Preliminary map showing the distribution of surficial materials in the Upper Mississippi River Basin (modified from Soller (1993). This map also shows the total extent of glaciation as well as the extent of late Wisconsinan-age glaciation in the basin.

SURFICIAL MATERIALS EXPLANATION

__T__ Till deposits and areas of discontinuous deposits with patches of exposed bedrock
__R__ Weathered Rock Materials and areas of exposed bedrock
__C__ Coarse-grained, stratified glacial-meltwater and postglacial alluvial deposits
__F__ fine-grained, stratified lake deposits
__L__ Wind-blown loess deposits, 20 feet or more thick
__M__ Late Wisconsinan Glacial Limit
__G__ Maximum Glacial Limit

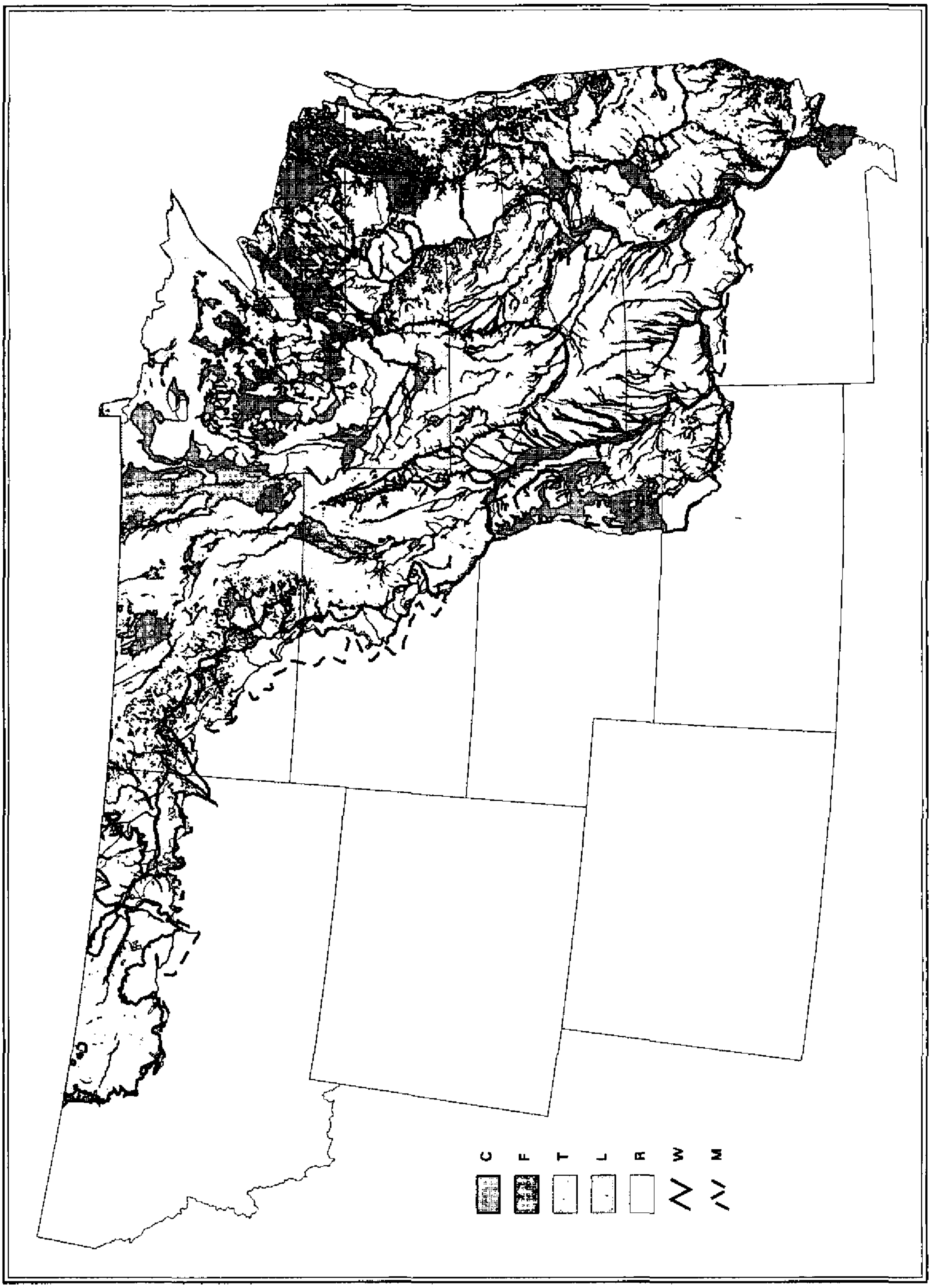

C
F
T
L
R
W
M

Figure 4.6 Soil orders are calculated from information from the STATSGO database of the U.S. Department of Agriculture, Soil Conservation Service. Map units in the 13 state-study area were clustered according to similar distribution of soil order. The soil order groups shown here are all heterogeneous, but are identified by the dominant order, and if appropriate, the soil order with the second and third highest proportion within the order group.

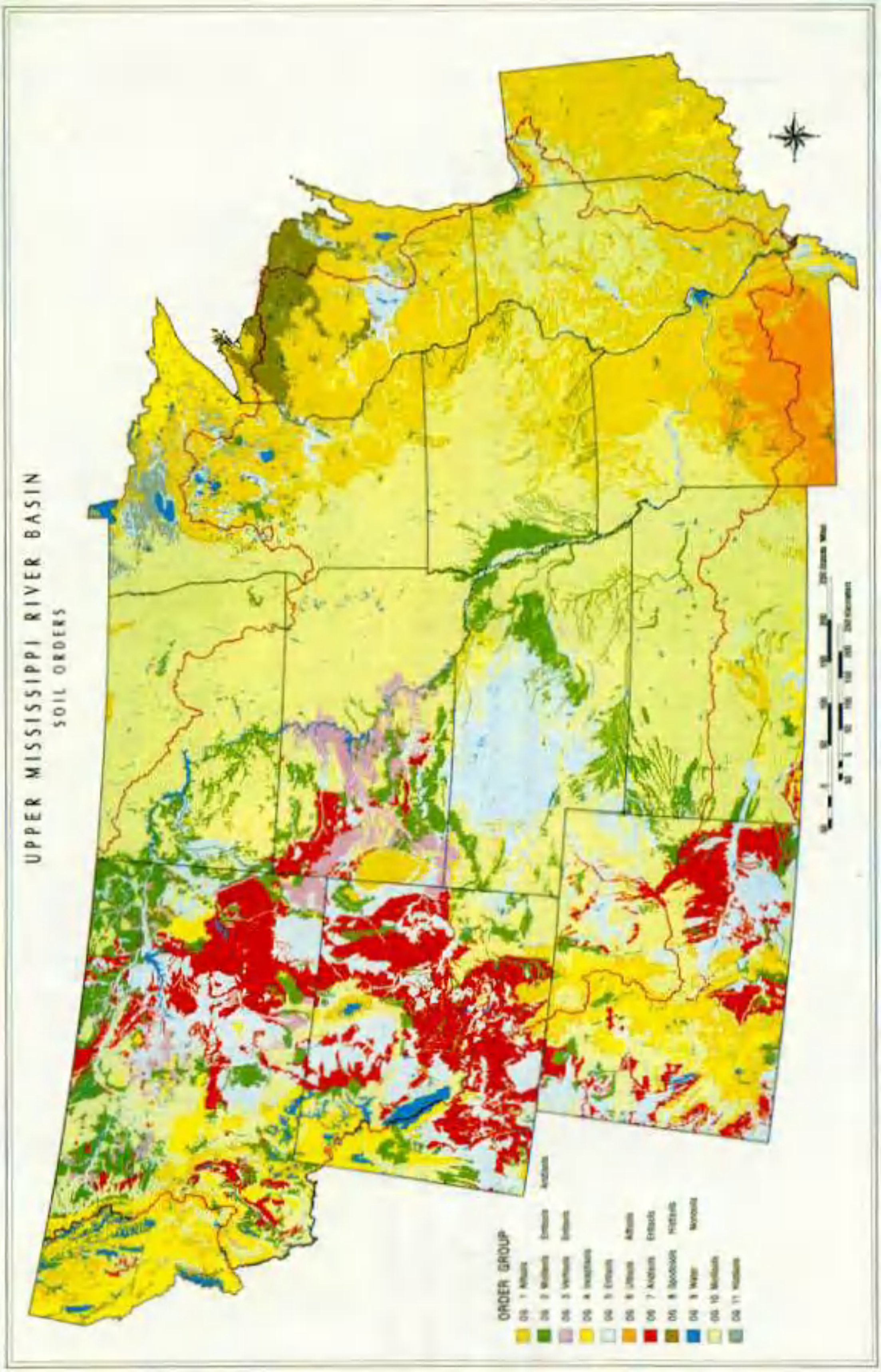
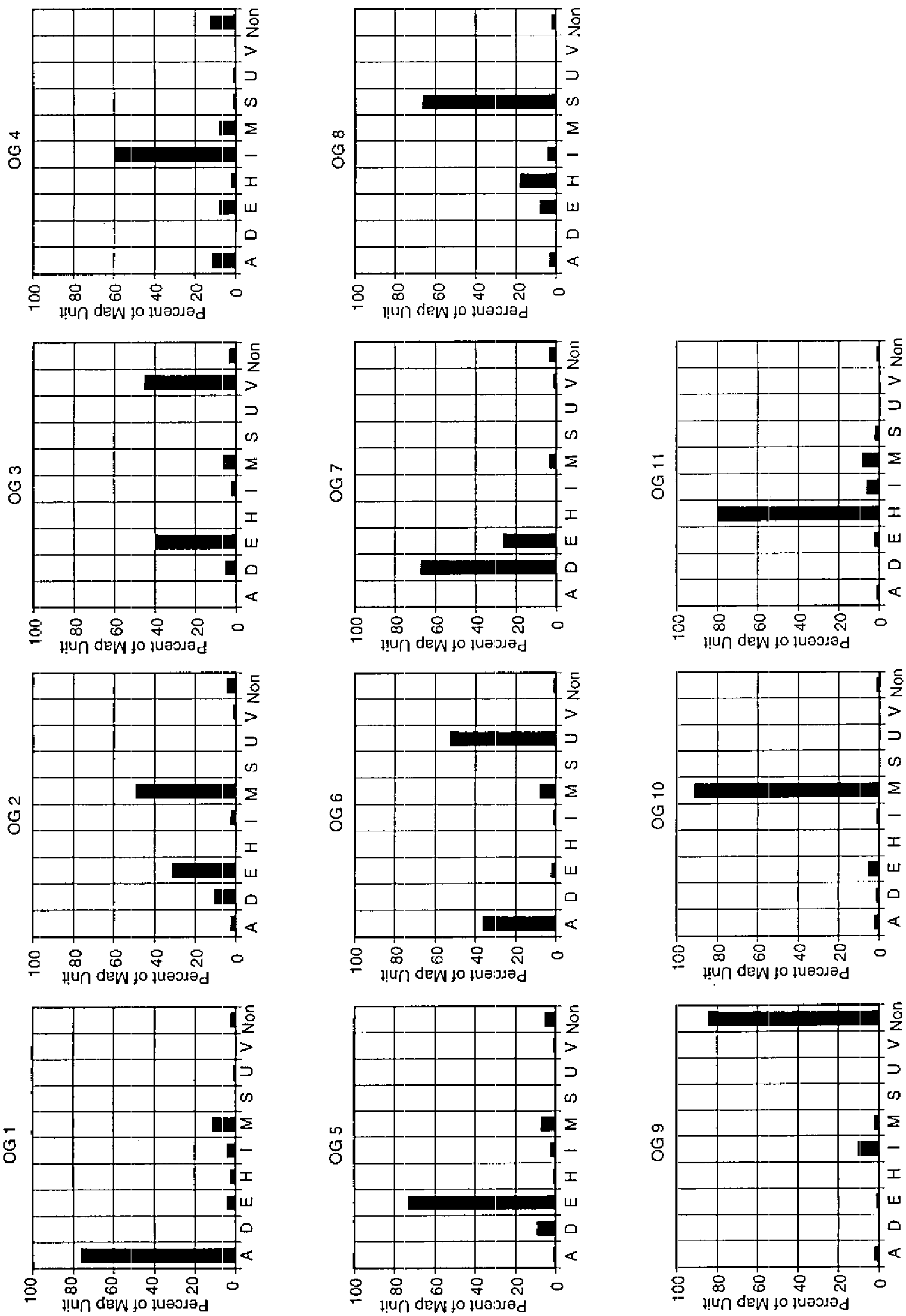

UPPER MISSISSIPPI RIVER BASIN
SOIL ORDERS
ORDER GROUP

Figure 4.7 Soil order groups formed by statistical clustering of the soil order patterns within STATSGO map units. For each soil order group, the area (in square meters, scientific notation) is shown. The codes are: A=Alfisols, C=Andisols, D=Aridisols, E=Entisols, H=Histosols, I=Inceptisols, M=Mollisols, O=Oxisols, S=Spodosols, U=Ultisols, V=Vertisols, Non= non-soils, such as rock outcrop and water. The map (figure 4.6) and statistics include all areas of the 13 state region, including areas outside the Upper Mississippi River Basin.


OG 1
OG 2
OG 3
OG 4
OG 5
OG 6
OG 7
OG 8
OG 9
OG 10
OG 11
Percent of Map Unit
0
20
40
60
80
100
A
D
E
H
I
M
S
U
V
Non

underlie valleys in the region, and relatively thick (more than 20 feet) wind-blown loess deposits that cover the other surficial materials in the uplands in the southern part of the region.

Distribution of Soils

The distribution of soils in the basin is presented by soil order in figures 4.6 and 4.7. Soil order is the most general class in Soil Taxonomy (Soil Survey Staff, 1975). A map of soil order groups (figure 4.6) was produced by calculating the proportions of soil orders in STATSGO map units, computing a multidimensional distance between the map units, and using a clustering algorithm to group the map units into a set of 11 soil order groups.

Figure 4.7 is a set of histograms showing the distribution of soil orders that make up each soil order group. The statistical clustering technique is used because the soil patterns are complex at this regional scale, but details on the distributions of soil properties are important to hydrologic analysis.

Mollisols are prairie soils that are formed under grasslands and have dark-colored surface layers and high base status (high natural fertility). Mollisols cover over 50 percent of the basin and are the dominant soil order in Montana, Colorado, North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, and Illinois, ranging from a high of 90 percent in North Dakota to a low of 9 percent in Wisconsin.

Alfisols are the dominant soil order in Wisconsin, Indiana, and Missouri. In the more humid eastern part of the basin, Alfisols formed under forest vegetation. In the extreme western part of the basin, Alfisols formed under a mix of deciduous, savanna, short and mid grasses, and forbs vegetation.

Hydric Soils

Hydric soils are important in the study area because they indicate the areas of pre-settlement wetlands. Hydric soils, as their name implies, are soils that have formed under wet conditions. These conditions must have been wet enough for the soils to become anaerobic in the upper part (National Technical Committee for Hydric Soils, 1991). Presence of hydric soils is considered an indication that an area may be or was formerly a wetland.

Figure 4.8 is a map of hydric soils as a percentage of the land surface, produced from the STATSGO database. Hydric soils in the basin occur as depressions (potholes) in young, late Wisconsinan-age glacial, closed drainage landscapes of the Dakotas, Minnesota, Iowa, and Illinois; in depressional areas on wide interfluve areas of southern Iowa and Illinois and northern Missouri; and in backland and backswamp areas on floodplains.

The area of hydric soils as a percentage of the total area of a state ranges from about 1 percent in Montana and Wyoming to over 35 percent of the area in Minnesota. The total area covered by hydric soils is about 26 million hectares (62 million acres) for the 13-state region. The area of hydric soils is considered roughly equivalent to the original area of wetlands before the region was settled.

The highest concentration of hydric soils in the basin is in the floodplains of the Missouri and Mississippi Rivers and in the glacial pothole and depressional (closed drainage) areas of central Iowa, southern Minnesota, the northern half of Indiana, and central and northeastern Illinois. A large portion of the hydric soils in this, the major corn-belt region of the basin, represents former wetlands (closed depressions) that have been drained for agricultural use.

The Missouri River has a relatively wide floodplain through Nebraska and Iowa. The pattern of hydric soils in the floodplain is such that the highest percentage of hydric soils is located away from the river and next to the uplands. This pattern conforms to landforms in the floodplain: natural levees next to the stream where sediment is deposited as a result of rapid loss in water velocity, backland areas that generally slope to backland depressions, and occasional oxbow lakes (Strahler, 1969; Ruhe, 1975).

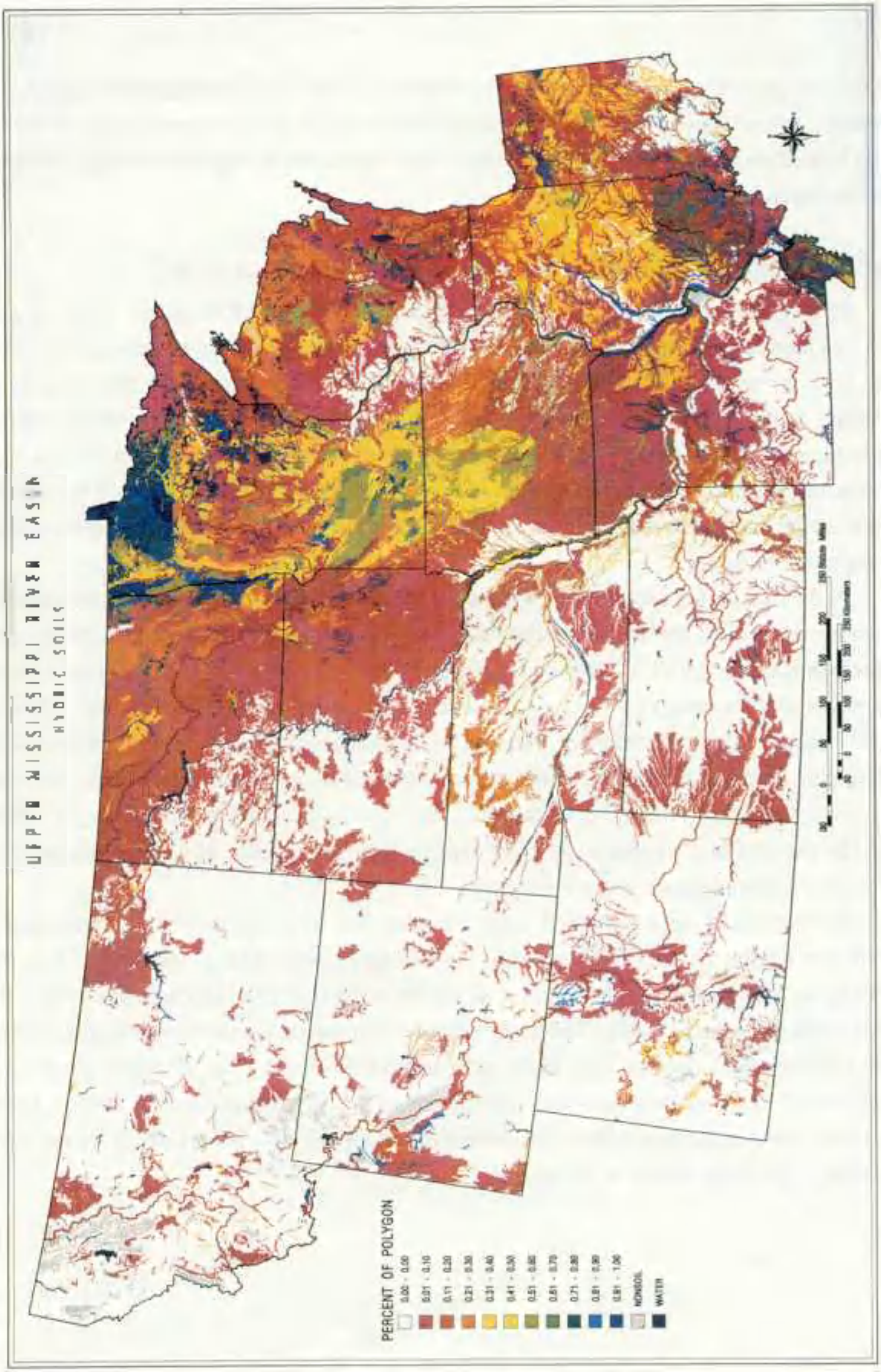
Topography

The basin is characterized by two distinct kinds of landscapes: (1) open systems where the drainage net grades from small streams to larger trunk streams, and (2) closed systems where the drainage is trapped within a common depository and where surface flow, if it occurs, is mostly in ill-defined drainageways to trunk streams (Ruhe and Walker, 1968). Within these landscapes, hillslope geometry (linearity, convexity, or concavity along the slope length and width) is an important factor affecting water movement. Convergent slopes, which are concave in both slope length and width directions, are areas of maximum accumulation of runoff water. These convergent slopes are potential storage areas of runoff water. In contrast, divergent slopes, which are convex in both directions, are areas of maximum runoff dispersion (Pennock and others, 1987).

In open systems, surface water runoff generally flows to a stream and out of the system. Water may accumulate in convergent areas of open landscapes such as head slopes (convergent back slope) and convergent foot and toe slope positions. These wetter areas may support hydric soils if there is a water-restricting layer that crops out on the hill slope.

Closed landscapes are generally related to the areas of glacial drift in the drainage basin. Closed landscapes lack well defined stream outlets: thus, water, sediment, and other materials from the surrounding area are trapped in potholes or other depressions. Trapped or ponded water must either evaporate or recharge the ground water. During large storms, the smaller depressions may fill and any excess water may overflow in undefined surface drainage to other depressions or eventually to a stream. Constructed open ditch drainage systems change closed landscapes so that

Figure 4.8 Hydric soils are calculated from information in the STATSGO database of the U.S. Department of Agriculture, Soil Conservation Service. Each map unit is an association of phases of soil series, and the proportion of each phase within the map unit is coded in the database. The proportions of the hydric soil phases are summed for each map unit.


UPPER MISSISSIPPI RIVER BASIN
HYDRIC SOILS
PERCENT OF POLYGON
0.00 - 0.00
0.01 - 0.10
0.11 - 0.20
0.21 - 0.30
0.31 - 0.40
0.41 - 0.50
0.51 - 0.60
0.61 - 0.70
0.71 - 0.80
0.81 - 0.90
0.91 - 1.00
NONSOIL
WATER

they function more like open landscapes with respect to both surface and ground water hydrology. Before agricultural drainage, closed landscapes were considered noncontributing with respect to surface water runoff, although they might contribute during storms large enough to cause the depressions to "fill and spill."

SURFACE AND SOIL PROFILE STORAGE OF WATER

In general, the surface water storage capacity is a function of slope and slope variance, that is, the amount and type of terrain variability there is over the average slope at a landscape scale. This can be determined from digital elevation data for specific storage capacities and flow directions. Surface water storage capacities are an attribute of the soils data as is the subsurface storage capacity. As improved digital elevation data and more detailed digital soils data become available more site specific digital analyses will become feasible. Current data are more suited to regional analysis at scales ranging from landscape to larger areas. Estimates based on existing data are quite revealing.

In the nine states comprising the detailed SAST study area, the potential for water storage both above the ground surface and in the soil is broadly estimated at 420 billion cubic meters, using information in the STATSGO soil database (table 4.1). This volume is equivalent to a water depth of 0.26 meters (10 inches) spread uniformly over the 1,631,000 square kilometer (630,000 square miles) area of the 9 states. This depth represents the average depth of surface ponding plus the average available water capacity of the soil, which is the difference between the field capacity and the wilting point of the soil. The volume of available water capacity can be divided by the land area to give an intuitive impression of the amount of water expressed as a depth (cubic meters / square meters = meters).

The combined surface and soil-water potential may be compared with accumulated precipitation depths for the June-September 1993 flood period, which ranged from 15 to 30 inches (figure 3.3b) and were about 4 to 6 inches for some individual storm events within that period (Wahl and others, 1993). The accumulated precipitation for the 8-month antecedent period, October 1992 through May 1993, also ranged from about 15 to 30 inches (figure 3.3). The equivalent depth of the water-year 1993 runoff of the Mississippi River at Thebes, Illinois spread over the 9-state area, is about 9.6 inches (table 3.1); the equivalent depth for the June-September 1993 flood season is 4.5 inches.

Table 4.1 Surface (available ponding volume) and subsoil (available water capacity) water storage for states in the Upper Mississippi River Basin.

State	Available Ponding volume 10^9 m^3	Available Water Capacity (AWC) 10^9 m^3	Total Water Storage 10^9 m^3	Ponding as % of Total Storage	AWC as % of Total Storage
Minnesota	10.8	55	65.9	16.4	83.6
South Dakota	2.76	36.4	39.2	7.03	92.97
North Dakota	4.43	39	43.4	10.2	89.8
Nebraska	0.62	42	42.7	1.45	98.5
Colorado	0.35	44.6	45	0.79	99.21
Montana	0.92	53.8	54.7	1.67	98.33
Wyoming	0.24	32.2	32.4	0.73	99.27
Kansas	0.90	52.8	53.7	1.68	98.32
Wisconsin	9.12	30.4	39.5	23.1	76.93
Illinois	14.5	39.6	54.1	26.8	73.24
Indiana	6.0	22.7	28.7	20.9	79.09
Iowa	0.57	41.5	42	1.36	98.64
Missouri	0.48	39.2	39.7	1.21	98.79
Total	51.6	529	581	8.89	91.11

Although the combined surface and soil water-storage capacity is large, it is effective in reducing peak flood runoff rates only if water enters it at a sufficiently high flow rate at the time the flood peak is occurring. For a given inflow rate, the reduction in the outflow rate equals the rate at which water enters into storage. During intense rains, the rate at which the soil can absorb water may be insufficient to effect a significant reduction in the outflow. Antecedent moisture conditions also are important. If the storage is filled before the peak occurs, water will not be able to enter storage at the critical time, and no reduction in peak flow will be achieved. During June and July 1993, many of the areas that received heavy rainfalls and experienced severe flooding had depleted buffering capacity because the soils and wetlands were wet and unable to store additional water.

Subsoil Water Storage

The ability of a soil to store water varies with texture, density, organic matter content, and initial moisture content of the soil. Figure 4.9 is a map of the available water capacity of soils, produced from the STATSGO data base. The available water capacities by state are given in Table 4.1. Available water capacity is defined as the difference between the water storage at field capacity (saturation followed by gravitational drainage) and at wilting point (plants cannot extract more water). Operationally, this is calculated as the water retention difference using laboratory methods. Total water storage at soil saturation would be somewhat greater since water stored between field capacity and saturation is included.

Infiltration rates are a particularly important factor in the potential water storage in soils. Most medium textured soils, such as those in the basin, have average infiltration rates of 1.25 to 2.5 cm/hr (0.5 to 1.0 in/hr) (Donahue and others, 1977). Storm rainfall intensities greater than those averages are not uncommon. These intensities will exceed the infiltration rates of many soils, and water will run off into streams in open drainage systems or into depressions in closed drainage systems, before the soil becomes saturated. The utility of the subsurface soil water storage capacity for flood reduction, therefore, is often limited by infiltration rates. In closed drainage systems, the detention of water in the depressions offers increased opportunity for infiltration to occur, but this infiltration may not be effective for reducing flood peak flows unless the depression is spilling water to the stream and the infiltration is synchronized with the flood peak.

Infiltration generally increases with an increase in organic matter, stability of soil aggregates, and soil cover. These properties are supported by management practices such as residue management and no-till systems. Structural practices such as terracing trap water on the soil surface and allow for seepage of water into the soil. These management practices increase infiltration and thus increase the ability of the soil to store water from rainfall. Additionally, transpiration of plants and evaporation from the soil surface lower soil moisture content. Thus, soils with dense live plant covers have more storage capacity available for water retention than soils with sparse or no live coverage.

Surface Water Storage

In the closed drainage areas of the basin, glacial landscapes with depressions or potholes will pond water. During small storms, these depressions do not fill, and the landscape does not contribute direct flood runoff to streams. During larger storms, the depressions may fill, and surface water may flow from pothole to pothole through an ill-defined drainage network and eventually find an outlet to a stream. However, flow in this ill-defined drainage network is a relatively tortuous process in comparison with open drainage systems, and the water in the depressions is still unavailable for runoff into the stream. For this reason, drainage areas in pothole regions often are designated as indeterminate. The area that contributes to a runoff event generally increases with increasing antecedent moisture conditions and storm volumes as the smaller potholes fill and spill.

Figure 4.10 is a map of surface water ponding, produced from the STATSGO database. The depth of ponding is recorded for each soil series, typically to the nearest half-foot. The depth of ponding was weighted by the area of the soil series within each map unit, to calculate an average depth of ponding for the map unit.

Surface water storage in the basin is confined to the late-Wisconsinan glacial till area (the prairie pothole region) of North and South Dakota, Minnesota, north central Iowa, and east central Illinois. The rest of the basin consists of open systems with only minor areas that store water on the surface. In the basin, estimates show 10 times more storage capacity in the soil than above ground. Subsoil storage is important in all of the basin, but in open drained areas, subsoil storage is the major component and has relatively high capacities in Iowa, Missouri, Kansas, Montana, Colorado, and Nebraska relative to other states. Relatively high surface water storage is found in the Dakotas, Minnesota, Illinois, Indiana, and Wisconsin.

While these analyses based on STATSGO data are valuable for regional estimations, more detail is necessary for subregional and local planning and decision making. The SCS is conducting and coordinating an effort to obtain soils data at a much finer resolution. These data, the Soil Survey Geographic Data Base (SSURGO), are being collected in map and digital form.

Recommendation 4.2: Accelerate production of soils data of finer resolution than the STATSGO data, e.g., SSURGO data, and include those data as part of the clearinghouse. The SCS should maintain these data for distribution in a generally accepted format that can be easily converted to other generally accepted formats.

WETLANDS OF THE UPPER MISSISSIPPI RIVER BASIN

Wetlands in the upland areas of the basin are discussed with respect to changes in wetlands from presettlement to the present, to their value for biodiversity and for water quality, and to their potential use for flood redirection in the basin.

Presettlement vegetation consisted of deciduous hardwood forests in the eastern Ozark Plateau parts of the basin, tall-grass prairies in the central part, and mixed and short-grass prairies in the western part. In the prairie region, woodlands occurred in riparian zones and around upland wetlands.

Figure 4.9 The available water capacity (AWC) of the soil is calculated from information in the STATSGO database of the U.S. Department of Agriculture, Soil Conservation Service. AWC has been reported in terms of inches of water per inch of soil or centimeters of water per centimeter of soil. In laboratory analyses, AWC is measured as the water retention difference. The AWC ratio is calculated from the midpoint of a range of AWC values for each layer. An AWC-volume measure is calculated for each component by multiplying the AWC-ratio by the thickness of the layer, summing the results over the layers, and multiplying by the area of the component. AWC-volume is divided by the area of the polygon to give an average AWC volume per unit of area that is used to classify polygons into legend categories. New volume per unit area ratios are calculated for the legend categories. The influence of rocks or stones in the soil is taken into account in the definition of AWC.

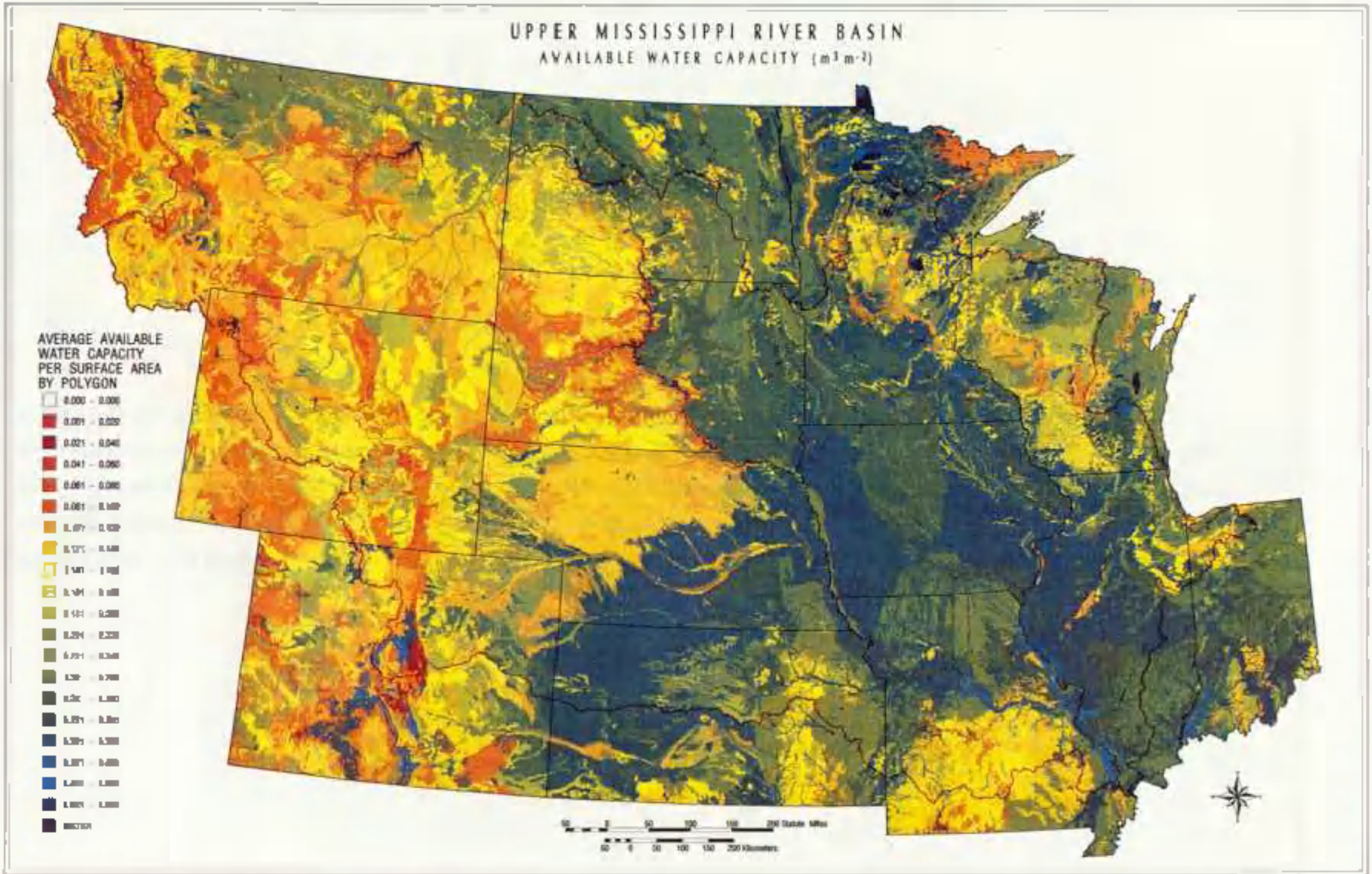
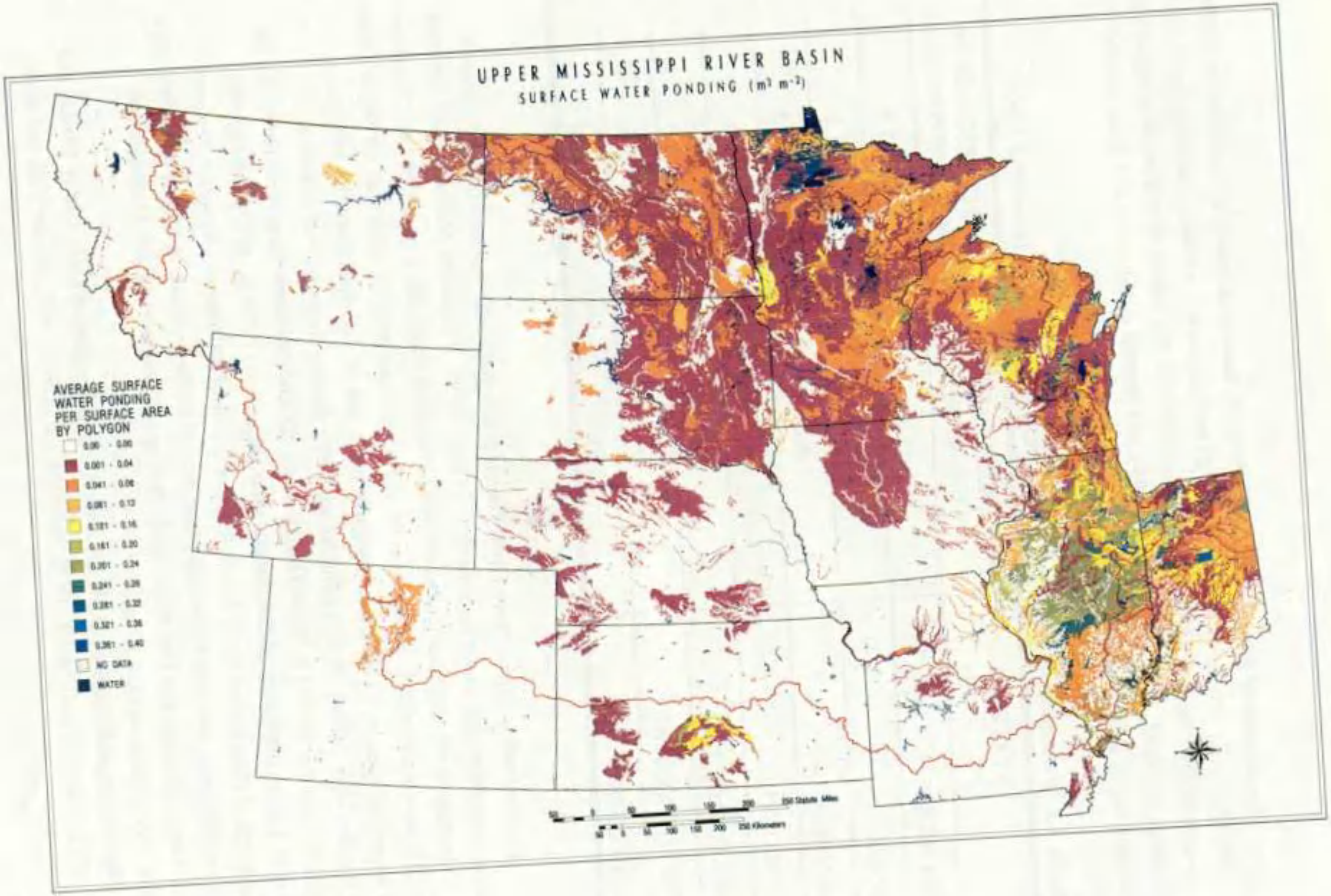

UPPER MISSISSIPPI RIVER BASIN
AVAILABLE WATER CAPACITY (m³ m⁻³)
AVERAGE AVAILABLE WATER CAPACITY PER SURFACE AREA BY POLYGON
0.021 - 0.040
0.041 - 0.060
200 Statute Miles
200 Kilometers

Figure 4.10 The surface water ponding (SWP) of the soil is calculated from information in the STATSGO database of the U.S. Department of Agriculture, Soil Conservation Service. The SWP is interpreted here as cubic meters of water per square meter of soil. Each map unit is an association of phases of soil series. The maximum depth of ponding for each phase is weighted by the areal proportion of the phase with the map unit and accumulated to give an average depth of ponding for the map unit in meters. This is equivalent to cubic meters of water per square meter of soil.


UPPER MISSISSIPPI RIVER BASIN
SURFACE WATER PONDING (m^3 m^{-2})
AVERAGE SURFACE
WATER PONDING
PER SURFACE AREA
BY POLYGON
0.00 - 0.00
0.001 - 0.04
0.041 - 0.08
0.081 - 0.12
0.121 - 0.16
0.161 - 0.20
0.201 - 0.24
0.241 - 0.28
0.281 - 0.32
0.321 - 0.36
0.361 - 0.40
NO DATA
WATER

The amount of presettlement wetlands in the basin is estimated at 58 million acres (Kusler, 1993; Table 4.2). Presently there are about 23 million acres of wetlands remaining in the basin (Kusler, 1993). The loss of 35 million acres of wetlands has mostly been a result of agricultural drainage (Kantrud, 1989; van der Valk, 1989), and channel modification and flood control (Funk and Robinson; 1974, Eckblad, 1988; Jahn and Anderson, 1986).

Table 4.2 Percentage of wetlands in States circa 1780 and present (after Dahl 1990)

STATE	PERCENTAGE OF WETLANDS 1780	PERCENTAGE OF WETLANDS PRESENT
ILLINOIS	22.8	3.5
IOWA	11.1	1.2
MINNESOTA	28.0	16.2
MISSOURI	10.9	1.4
NORTH DAKOTA	10.9	5.5
SOUTH DAKOTA	5.5	3.6
WISCONSIN	27.3	14.8

The wetlands in the northern Great Plains (prairie potholes) and sand hills are critical to breeding, migration, and wintering waterfowl (Tiner, 1984). The prairie pothole region occupies only 10 percent of the total continental waterfowl breeding range, but it produces over 50 percent of the continental waterfowl. Wetlands in the prairie potholes provide cover and nesting to a total of 15 waterfowl species, 57 species of nongame birds, and 39 mammals (Kantrud and others, 1989; van der Valk, 1989). Prairie potholes support a diverse community of invertebrates including 44 mollusk species in North Dakota alone. Drained wetlands (prairie potholes) can be restored to a close semblance of their natural state (Kusler and Kentula, 1990), and typically recover much of their former biotic function within a year of restoration. However, restored wetlands consistently have less biodiversity than natural wetlands within at least the first few years of restoration (LaGrange and Dinsmore, 1989; Delphy and Dinsmore, 1993; Hemesath and Dinsmore, 1993; Galatowitsch, 1993).

Depressions and fringe wetlands are critical to preservation of water quality (Reddy and Patrick, 1975; Gambrell and Patrick, 1978; Johnston and others, 1990; van der Valk and others, 1979; Mausbach and Richardson, 1994). Precipitation, runoff, topography, pedology, and vegetation affect the extent to which a wetland can enhance water quality (Furness, 1983; Wigham and others, 1988). Wetlands where the soil becomes anaerobic can remove excess nitrates from the soil and water through denitrification processes, and wetlands reduce nitrate to nitrogen gas (Gambrell and Patrick, 1978). Gambrell and Patrick (1978) also show that wetlands help degrade agricultural pesticides to environmentally safer compounds. Wetlands also serve as sinks for phosphorous (Mitsch and others, 1977; Johnston and others, 1984). Wetlands serve as natural filters that prevent sediments from entering lakes and streams thus enhancing surface water quality (Kusler and Brooks, 1988).

Role of Wetlands in flood reduction

Pleistocene glaciation significantly modified the landscapes of the upper reaches of the Mississippi and Missouri Rivers. The morphology of these landscapes in the northern prairie region consists of end moraines, stagnation moraines, ground moraines, outwash plains, and lake plains. The upland areas contain numerous glacial depressions of various shapes, sizes, and depths that store runoff. Most wetlands in the prairie pothole region occur within depressions in end moraines and ground moraines. Local relief from hilltop to adjacent lowland may be 15 to 45 meters in end moraines and only a few meters in ground moraine (Winter, 1989).

Closed flow systems are still common in the basin, covering thousands of square miles. These landscapes do not normally contribute to stream flow by runoff, except during storms large enough to make the depressions fill and spill. Therefore, they do not fit the classical definition of "watershed" unless they are artificially drained. Winter (1989) states that, "Where it is not extremely flat, such as in morainal areas, a natural drainage network has not developed, and the many depressions are not connected by an integrated drainage system". More than 1,000 square miles of the 1,760 square mile drainage area above the Jamestown, North Dakota, reservoir are still considered to be noncontributing to runoff (due to absence of artificial drainage) (Wiche and others, 1990). Future drainage would convert these closed systems to open systems.

The primary loss of water in these closed landscapes is through evapotranspiration and groundwater seepage. Average annual evaporation amounts in inches vary among reservoirs in the Midwest from north to south and from east to west: Milwaukee (29); Minneapolis (32); Bismarck (39); Havre (43); Kansas City (47) and North Platte (51) (Van der Leeden and others, 1991). Kantrud and Steward (1977) studied the water losses from 135 wetlands of different water regimes over a 6- year period. On the average, wetlands are either dry or their water depths are substantially reduced by the time of the November freeze-up. In an average year, therefore, the depressions are available for runoff storage the following spring.

In contrast, thousands of square miles of depressional areas have been drained in the basin. Wetlands as a percentage of surface area of many states have declined drastically since the initiation of European settlement in the 1780's (table 4.2).

Recommendation 4.3: The U.S. Fish and Wildlife Service should complete the National Wetlands Inventory. Agricultural wetlands should be included. This classification would improve the usefulness of the data set for evaluating areas of wetlands and for local and subregional entities to use in planning.

Investigators have documented the depressional storage in some of the closed flow systems within the northern prairie portion of the Upper Mississippi River Basin. Wiche and others (1990) used digital elevation models in 5 test sites covering 26.4 square miles in North Dakota. Total storage capacities were 809.8, 330.5, 326.3, 321.8, and 199.2 acre-feet per square mile. Equivalent depths of stored water were 15.2, 6.2, 6.1, 6.0, and 4.7 inches. Hubbard and Linder (1986) measured the water held in 213 wetlands representing 50 percent of the surface water of the study area in South Dakota. These wetlands held about 162 acre-feet (20 ha-m) of water; the equivalent depth of stored water was 3 inches for the pothole area of the basin. The authors concluded that immense quantities of runoff could be impounded by prairie wetlands, acting to limit flooding and to recharge groundwater supplies. Ludden and others (1983) studied wetland storage capacities in the Devil's Lake Basin of North Dakota. They found that the wetlands in the area store about 72 percent of the total runoff from a 2-year frequency flood and about 41 percent of the total runoff from a 100-year frequency event. The Devil's Lake Basin itself is a large closed flow system that does not contribute to the Red River watershed.

Moore and Larson (1979) studied the effects of drainage projects on surface runoff from small depressional watersheds throughout the North central region of the United States. They were interested in the role played by prairie pothole depressional wetlands in regulating high rates of runoff (flood flows) from major summer storms and from spring snowmelt, before and after drainage for agriculture use. In 23 watersheds in Minnesota, they determined that the mean annual flood increases in proportion to watershed area and inversely with the percentage of lakes and wetlands within the watershed. Their data support the contention that artificial drainage increases the watershed runoff area and decreases the amount of depressional storage. On the other hand, Lindsley and Franzini (1972, p 626) note that, although there is no question about the value of watershed storage and land treatment for reduction of soil erosion and preservation of soil moisture, there is debate about their value for flood flow reduction. Also, Miller and Frink (1984) found that the year-to-year variability of flood flows in the Red River of the North basin may have masked any small effects of drainage of potholes of agricultural lands.

Theoretical consideration of the relations between inflows, outflows, and storage changes suggests that the effectiveness of wetlands and soil moisture storage in reducing flood peaks will be greatest for small floods with dry antecedent conditions, and least for floods like 1993 in which all available storage is full before the peak occurs.

Identification of Noncontributing closed landscapes

Noncontributing landscapes in the uplands store a considerable amount of water. Some scientists argue that closing formerly noncontributing landscapes can increase upland water retention with the effect of reducing flood peaks. Wilen (FWS, written commun., 1994) suggests identifying the formerly noncontributing landscapes and calculating the amount of retention that would be obtained by decreasing the artificial drainage in those areas. A rough estimate can be obtained by identifying the closed landscapes, identifying the systems that have been opened by artificial drainage, calculating the storage capacity under both conditions, and calculating the difference. Using GIS and detailed data produced by adding the agricultural wetland category to the NWI data would allow the calculation to be accomplished at the individual wetland scale as well as in aggregate. A refinement of this calculation could be made by incorporating the effect of water storage retention under various storm conditions and using the estimates of runoff conditions caused by agricultural management practices.

CONCLUSIONS

The terrain classification system is crucial to understanding the hydrologic response of the basin. The terrain classes will allow analysis of research results on hydrologic process within areas of similar terrain. This analysis is needed to understand how parts of the basin and the basin as a whole respond to various land use and land treatment activities. Further analysis of the STATSGO database is needed to develop thematic maps that show areas of similar hydrologic response. A multidimensional distance and clustering analysis similar to the slope analysis presented in this report is needed for soil properties related to hydrologic response. These properties include slope, permeability, hydrologic group, texture, and available water capacity. This analysis will support development of the terrain classification system by providing attribute information for the terrain classes.

The effect of management practices that increase infiltration of water into the soil needs further study with respect to hydrologic response of the basin. Questions to be answered are (1) does increased storage of surface water reduce peak flows and stages, and for which types of floods? (2) what is the effect of increased infiltration on groundwater flow and groundwater quality? and (3) for which terrain classes are these practices most effective?

The restoration of wetlands is important for reducing surface water flow in certain landscapes. Further study is needed to identify the terrain classes that are most affected by surface water storage.

Chapter 5

FLOODPLAIN GEOMORPHOLOGY

DIFFERENT RIVERS - DIFFERENT REACHES - DIFFERENT FLOOD IMPACTS

Comparison of the physical effects of the 1993 floods on the upper Mississippi and Missouri Rivers shows that river reaches in broadly similar physiographic regions may respond very differently during floods. A fundamental conclusion based on the comparison of the Upper Mississippi and Missouri Rivers is that each river and its associated floodplain is distinct. Although these two rivers and their larger tributaries share a number of common features and glacial meltwater drainage history, significant differences in river discharge and slope, floodplain width, and sediment load strongly affect flood response. For example, the annual discharge of the upper Mississippi River is generally comparable to the annual discharge of the Missouri River, but the sediment yield of the Missouri averages more than 5 times that of the upper Mississippi. Thus, the average slope of the lower Missouri River floodplain is adjusted to the sediment load and is about twice the slope of the middle Mississippi River floodplain downstream from the confluence of the two rivers. Moreover, the floodplain of the lower Missouri is, on average, about half the width of the floodplain of the middle Mississippi. Consequently, impacts of the 1993 flood were dissimilar along these two rivers. Levee breaches along the lower Missouri commonly resulted in high-velocity flows across its relatively narrow and relatively steep floodplain. These high-energy flows caused extensive deep scour and thick sand deposition across prime agricultural bottomlands. In contrast, levee breaches along the middle Mississippi produced fewer areas of intense erosion and sedimentation, and impacts were largely limited to passive inundation of large bottomland tracts.

Separate reaches along the same river also exhibit significant geomorphological, hydrological, and ecological differences. Along the reach immediately downstream from Gavins Point Dam, the Missouri River presently is deepening its channel (Hesse and others, 1989a). However, south of its confluence with the Platte River, channel aggradation is the present norm. Further downstream, aggradational and depositional tendencies appear to be approximately balanced. More locally, within the relatively narrow floodplain of the lower Missouri between Glasgow and St. Charles, Missouri, local reaches characterized by tight (high amplitude, short wavelength) meanders served as principal locations for extensive deep scour and concomitant deposition of thick sand deposits. Within these local reaches, as much as 30 percent of the floodplain was severely damaged by these processes; elsewhere such damage was limited, on average, to less than 7 percent of the floodplain.

GEOMORPHOLOGY AND SURFICIAL GEOLOGY OF THE LOWER MISSOURI RIVER VALLEY

The lower Missouri River study area for geomorphic analysis extends from Harpst Island, north of Leavenworth, Kansas, to the mouth of the Missouri at its confluence with the Mississippi River at St. Louis. The northern part of the area is located in the glaciated plains of the Central Lowlands physiographic province. The southern part runs along the northern fringe of the nonglaciated Osage Plains. South of Glasgow, the area includes the northern part of the Ozark Plateau and a small part of the Central Lowlands province near the river mouth. Throughout the study area, the Missouri River channel is bordered by broad flat bottomland areas (figure 5.1), 2 to 10 miles wide, that are incised 200 to 400 feet below the adjacent upland surfaces. The river channel is 412 miles long; the adjacent floodplain extends 328 linear miles, measured along the river channel belt. The surface slope of the river averages about 1 foot per mile, whereas the slope of the adjacent floodplain area is about 1.2 foot per mile. Major tributaries in the study area, from north to south, the Kansas, Grand, Chariton, Little Chariton, Lamine, and Osage Rivers.

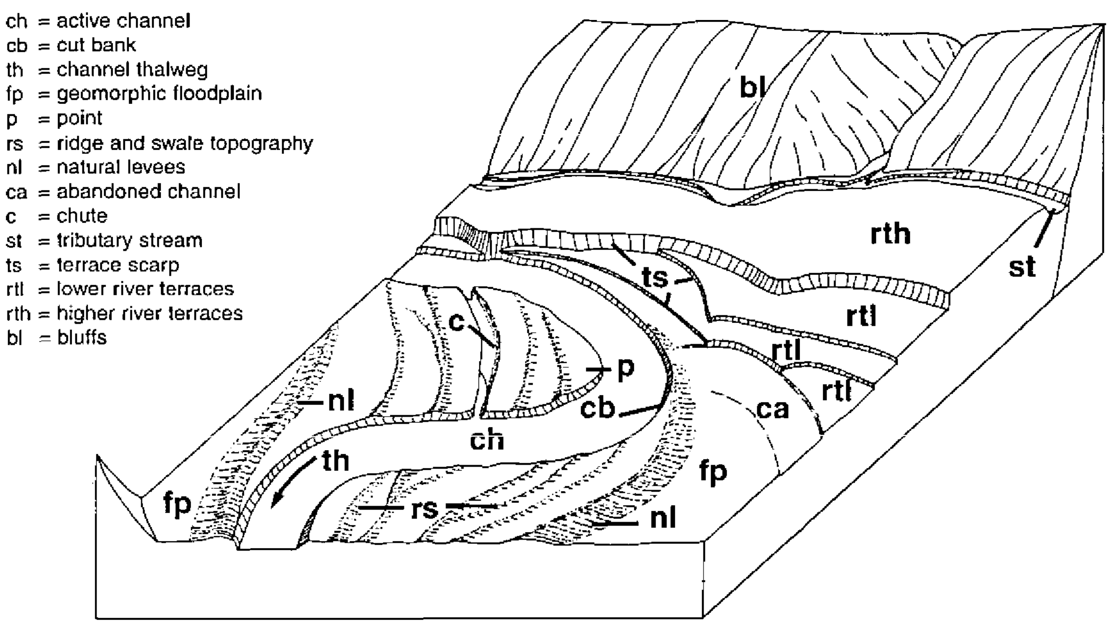


Figure 5.1. Natural morphologic features of the Missouri River floodplain.

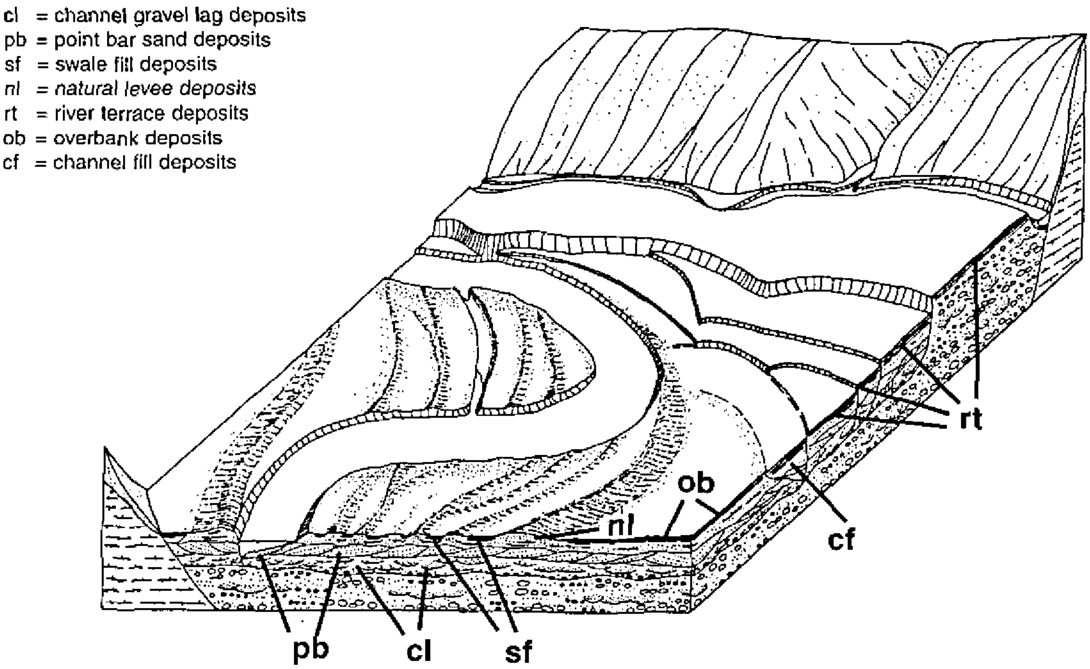


Figure 5.2. Conceptual model of Missouri River floodplain stratigraphy.

The area is underlain by interbedded shale and limestone bedrock (McCracken and others, 1961), which is covered by thin weathered-rock materials south of the Missouri River and by glacial till and local stratified meltwater deposits north of the river (Whitfield and others, 1993). Wind-blown loess deposits form a surface cover in the adjacent uplands, on valleyside bluffs, and on some high river terraces. Loess deposits range in thickness from less than 3 feet to more than 60 feet. Valley-filling sediments are composed primarily of highly permeable glacial outwash sand with intermixed gravel (figure 5.2). These deposits fill pre- and interglacial buried river valleys (Heim and Howe, 1963) and underlie all bottomland areas. These deposits commonly are 60 to 80 feet thick in the valley below Glasgow, and more than 100 feet thick in some areas between Kansas City and Glasgow. Postglacial river alluvial deposits overlie the outwash in lower floodplain zones (figure 5.2). The alluvial deposits consist of sand and pebble gravel in the lower part and contain interbedded sand, silt, and clay in the uppermost 6 to 15 feet. These finer-grained deposits are generally thin and patchy, except on terraces and along valley margins remote from the present channel where fine-grained deposits dominate the upper part of the alluvium. Alluvial deposits are estimated to be 35 to 45 feet thick beneath the modern floodplain and river terraces (based on maximum depths of historic channels and thickness of overbank deposits).

The floodplain of the lower Missouri River study area is divided into two parts that contrast geomorphologically. The northern part extends from Harpst Island, Kansas, to Glasgow, Missouri; the southern part extends from Glasgow to the river mouth at St. Louis. The floodplain of the northern part of the study area consists of two segments. From Harpst Island to Independence, Missouri, the valley is narrow (1.5 to 2.9 miles wide) and trends southeast and east. Bedrock crops out only locally in river bluffs that are capped by thick loess. The river channel forms a series of meanders that generally extend from bluff to bluff. From Independence to Glasgow, the bottomland widens to as much as 10 miles, and river flows in straight and large-meander reaches (figure 5.3). The bottomland contains several low (3- to 10-feet high), subtle, riverward-facing scarps. These scarps typically follow the general trend of the river channel belt and bound low river terraces, locally known as benches. In the highest of these terraces, northeast of Malta Bend and east of Waverly (figure 5.3), the surface of the alluvial deposits beneath the thick loess cover is about 30 feet above the floodplain adjacent to the river. In this reach, the area between the river channel and the terrace-bounding scarps generally occupies less than 50 percent of the bottomland. The floodplain in the river channel belt and the low terraces is characterized by a ridge and swale microtopography with local relief of 1 to 6 feet (figure 5.1). Former channels commonly bound the terrace scarps on their riverward side. In this river reach, tributary streams have eroded channels across the river terraces and along the edges of terraces at the base of the valleyside bluffs.

The floodplain of the lower 180-mile length of the lower Missouri River study area, between Glasgow and St. Charles, averages about 2.1 miles in width (figure 5.4). The surrounding upland surface is underlain by almost flat-lying carbonate bedrock (limestone and dolomite). Bedrock crops out virtually continuously along the valley bluffs. Because the valley is relatively narrow throughout this lower reach, the meandering river channel divides the floodplain surface into distinct segments, each of which is almost completely bounded by the river channel and the valley sides. These areas, locally termed "bottoms", occur as two distinct morphologic types: (1) the loop bottom, a relatively small, roughly equant bottomland area bounded by a single, continuously curving meander loop, and (2) the long bottom, a large, roughly rectilinear segment, bounded by a straight channel reach which typically runs along the valley wall (figure 5.4).

As noted by Schmudde (1963), the surface of each long bottom is interrupted by one or more, low (3- to 10-feet high), subtle but noticeable, riverward-facing scarps. These scarps typically subparallel the general trend of the river channel, but are commonly set back from it as much as one mile or more. The area between the river channel and these terrace-bounding scarps generally occupies between 25 and 75 percent of the floodplain. These lower bottomland surfaces are characterized by ridge and swale microtopography with an undulating relief of 1 to 6 feet.

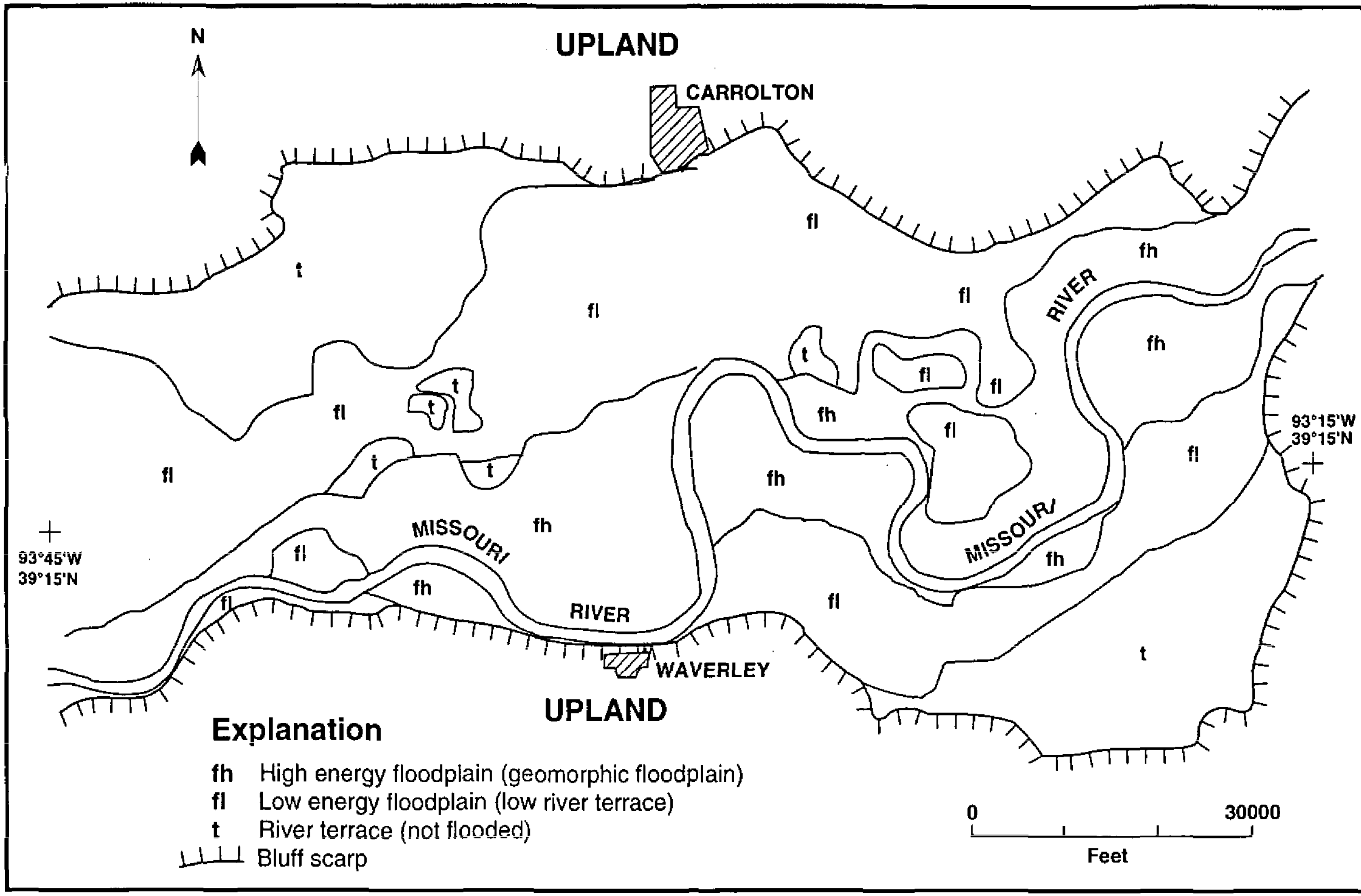


Figure 5.3. Missouri River floodplain zones in the Carrolton/Waverly area (Marshall, Missouri 1:100,000-scale map sheet). Within this broad reach (which is typical of the Missouri River floodplain between Kansas City and Glasgow, Missouri), several large terraces were not inundated by the 1993 floods and high energy bottomlands are generally confined to a 2- to 4- mile-wide zone immediately adjacent to the river channel.

Vestiges of former channels commonly bound the terrace scarps on their riverward side; the deeper channels may retain water through much of the year and thus represent significant potential for wetland restoration within these active bottomland areas.

In contrast, terraces and terrace scarps seldom occur within loop bottoms. However, loop-bottom surfaces are typically very similar microtopographically to the lower surfaces of the long bottoms. The characteristic ridge and swale microtopography of these surfaces typically extends diagonally downvalley from the upstream channel side of the bottom towards the opposite valley margin. Surface elevation and ridge and swale definition diminish in the same general direction.

An important characteristic of the Missouri River has been the migration of its channel meanders (mostly prior to 1950) and the concomitant reworking of its floodplain deposits. On average, these reworked areas comprise approximately one third of the entire floodplain area. However, loop bottoms, particularly their downstream portions, have been almost completely reworked by historic channel migration.

Between Kansas City and St. Charles, the average longitudinal gradient of the Missouri River averages about one foot per mile. However, the downstream gradients of individual loop bottoms may be significantly steeper than this average. Consequently, the upstream bank of a loop bottom may be as much as 5 feet higher than the downstream bank of the neighboring bottom immediately upstream. The local depositional buildup of sandy overbank deposits along the upstream margins of loop bottoms is largely responsible for this difference in height. Therefore, where unprotected by levees, the downstream portions of the loop bottoms typically are flooded first. This backwater overflow has little velocity and, therefore, limited competence to transport bedload. Thus, deposits from backwater flooding are generally thin and widely dispersed. However, where active overflow is channeled along existing elongate depressions (such as abandoned channels, chutes, or point-bar swales) sufficient flood-flow velocities may be maintained either to scour or at least to transport relatively coarse sandy bedload materials. Consequently, these elongate depressions often serve as principal locations for deposition and scour, particularly on loop bottoms.

During the 1993 flood, for example, sandbars often more than 1 foot thick were deposited within and beyond riparian fringes along the channel banks on upstream sides of meander loops. Beyond this riparian fringe, these deposits thin and terminate within a few hundred feet of the trees. Similar overbank bar deposits within and adjacent to this riparian fringe have also been documented for previous historic floods (Schmudde, 1963).

The Missouri River reach near Glasgow is the area in which the northern and southern parts of the study area converge. This reach exhibits features and modern land use of the wide-floodplain area that extends upstream, and the narrow-floodplain area that extends downstream

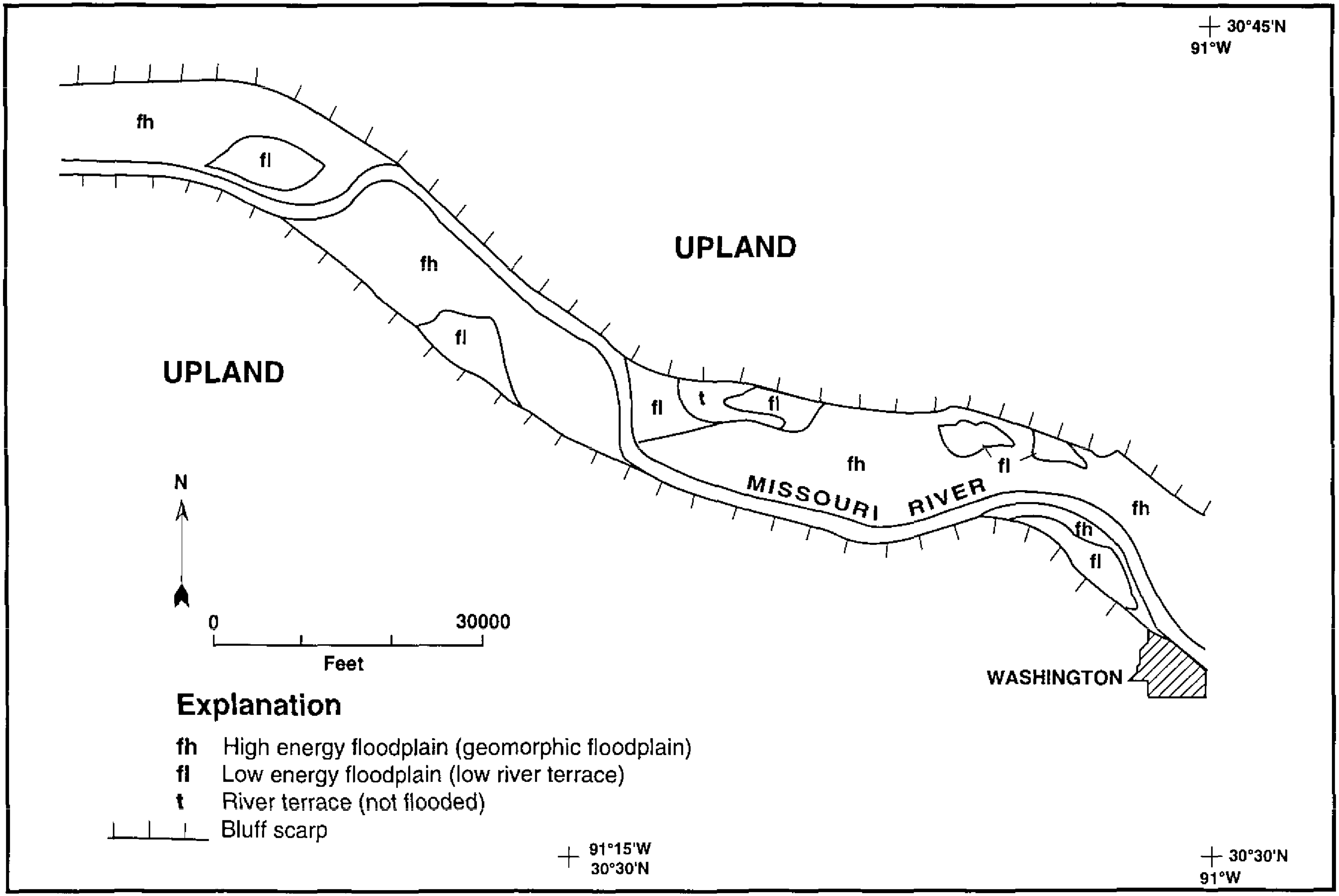


Figure 5.4. Missouri River floodplain zones in the Hermann/Washington area (Fulton, Missouri 1:000,000-scale map sheet). Within this narrow reach (which is typical of the Missouri River floodplain between Glasgow and St. Charles, Missouri), the floodplain is dominated by high energy bottomlands. During the 1993 floods this reach was inundated bluff to bluff.

(figure 5.5). Historic river channels show the recent pattern of downstream migration of meander loops through the lower part of the reach (figure 5.6). The 1993 record flood in this area extended bluff-to-bluff, and covered the emergent terraces shown in the image that was obtained during the falling flood stage of the large flood of September, 1993 (figure 5.7). The post-1993 flood image shows the effects of scour and sand deposition related to breached agricultural flood-control levees, highway and railroad embankments, and bridge piers (figure 5.8). The combined pre- and post-flood image (figure 5.9) displays details and high resolution of flood sand deposits.

FLOODPLAIN ZONES

For the purposes of this report, the term floodplain is used in a general sense and refers to all of the alluvial surfaces adjacent to a river channel that can be inundated by large floods. During the 1993 flood, floodplains along the upper Mississippi and Missouri Rivers were inundated when the river stages exceeded the design elevations of flood-control levees or when the levees failed; more than 90 percent of the total floodplain area was inundated.

The floodplains of the lower Missouri and middle Mississippi Rivers can be divided into at least 4 flow-energy zones (figure 5.1, 5.3, and 5.4): (1) the active river channel -- artificially constrained into a relatively deep, narrow channel by the wing-dams, revetments, and other channel structures of the present navigation-channel system; (2) the active high-energy floodplain (the geomorphic floodplain) -- land adjacent to the existing river channel constructed by the river in its natural and present, structurally-controlled regime. This zone encompasses the historic - recently prehistoric channel belt, which is delineated geomorphically by abandoned meander channels, ridge and swale point bar morphology, chutes and cutoff channels, and natural levees; (3) the low energy floodplain -- one or more (low, intermediate, or high) river terraces marginal to the active floodplain area that represent higher, older (middle to early Holocene or late Pleistocene in age) levels of the river. These surfaces generally lack the characteristic microtopography of the high-energy zone; small streams have eroded shallow channels across most terraces. (4) the highest river terraces (late Pleistocene or older in age) that were not flooded by the 1993 record flood.

These natural floodplain zones were impacted differently by the 1993 and earlier floods. The high-energy floodplain was actively flooded to depths of 10 to 15 feet, and extensive areas of deep scour and thick sand deposition were created by local concentration of the rapidly flowing flood waters during rising (figure 5.10) and maximum flood stages (figure 5.11). Low river terraces were less energetically inundated to depths of 3 to 10 feet and were subjected to much fewer and less extensive areas of scour and deposition. Higher terraces were passively flooded to lesser depths; the highest river terraces were not flooded (figure 5.11).

Recommendation 5.1: The USGS, SCS, NBS, and USACE should initiate a scientific research program to conduct detailed geomorphic/hydrologic/topographic mapping of the lower Missouri River floodplain and selected upper and middle Mississippi River floodplains to develop an overall geomorphic physical-process model, stratigraphic framework, and geotechnical database. The program would identify floodplain zones of variable flood risk and would include analysis of the age of floodplain zones, sedimentation rates, and the record of prehistoric large floods.

RIVER REGIME CONTROLS

Factors that affect river stage and flow (regime) include river discharge and velocity, channel width, depth and slope, sediment volume and grain size, and bank erodability. Various river reaches are also affected by the width of the active, high-energy floodplain and by the position of bounding bedrock bluffs and (or) by the presence of bedrock outcrops within the floodplain and channel. Along the lower Missouri River, artificial changes also have significantly affected river regime and flood flow. These changes include channel shortening by about 46 miles in Missouri (Funk and Robinson, 1974), channel narrowing from braided reaches more than one mile wide to a single channel as little as 800 feet wide (Hesse, 1989a; Schmulbach, 1992), concomitant reduction of total channel surface area by about 50 percent, and flow constriction by bridges, embankments, and channel-control structures. The present structurally controlled channel is designed to be 9 feet deep and self-sustaining by adjusted sediment transport and regulated discharge. Hydraulic models for the Missouri River below Gavins Point (Latka, 1993) indicate that 98 percent of the previous, natural channel was less than three feet deep during median flow discharge in late summer and autumn. In the present regulated channel, 87 percent of the river is less than 3 feet deep during similar flow conditions, but the navigation channel remains at design depth.

Figure 5.5. Landsat TM image of pre-1993 flood conditions near Glasgow, Missouri (September 24, 1992 image; path 25, row 33). As the distribution of agricultural fields clearly shows, nearly all of the floodplain was under cultivation before the 1993 flood. Wetland areas were essentially limited to the active main stem channel, tributary channels, and immediate adjacent areas. Only one large oxbow lake (upper left) remained viable.

Pre Flood (1992)

Figure 5.6. Map showing the 1879 channel, 1879 land cover/land use, and the present river channel near Glasgow, Missouri. Areas of intersection between the present channel and the 1879 channel were particularly prone to levee breaching that resulted in the erosion of deep scour holes and related deposition of thick sand deposits.

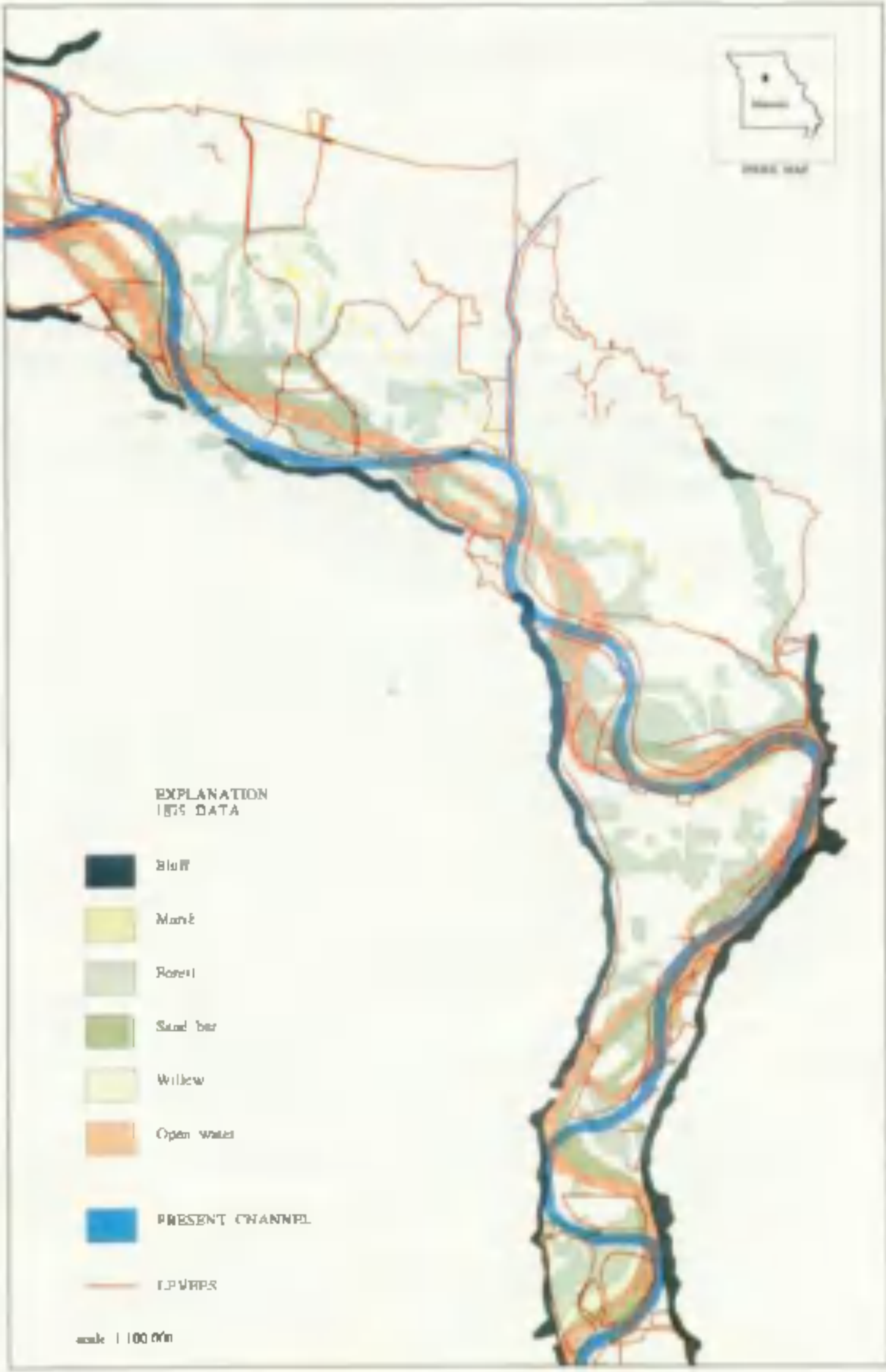

EXPLANATION
Bluff
Marsh
Forest
Sand bar
Willow
Open water
PRESENT CHANNEL
LEVEES

Figure 5.7. Landsat TM image showing near maximum stage of the late September, 1993 flood peak near Glasgow, Missouri (September 1993 image; path 25, row 33). Downriver from Glasgow the extent of flooding was essentially bluff to bluff. Upriver from Glasgow on the northeast side of the floodplain, terraces (predominantly light brown and tan) were not flooded during the September peak.

Sept. '93 Flood

Figure 5.8. Landsat TM image of post-1993 flood conditions near Glasgow, Missouri. Within the floodplain, dark blue delineates areas of water; blue-grays and olive greens indicate water saturated land; white to light gray indicate areas covered with thick sand deposits; and bright yellow to yellow green areas showing prominent field patterns delineate high terraces flooded in July but not in September (October 4,1993 image; path 26, row 33).

Post Flood (Oct 93)

Figure 5.9. Combined pre- and post-flood Landsat images of the Glasgow, Missouri area. Black delineates areas of water during both 1991 and 1993; blue delineates additional areas of water at the time of the October 1993 image; light yellow to brown areas showing prominent field patterns delineate terraces that were flooded in July 1993 but not in September 1993.

Pre-Flood vs Post Flood

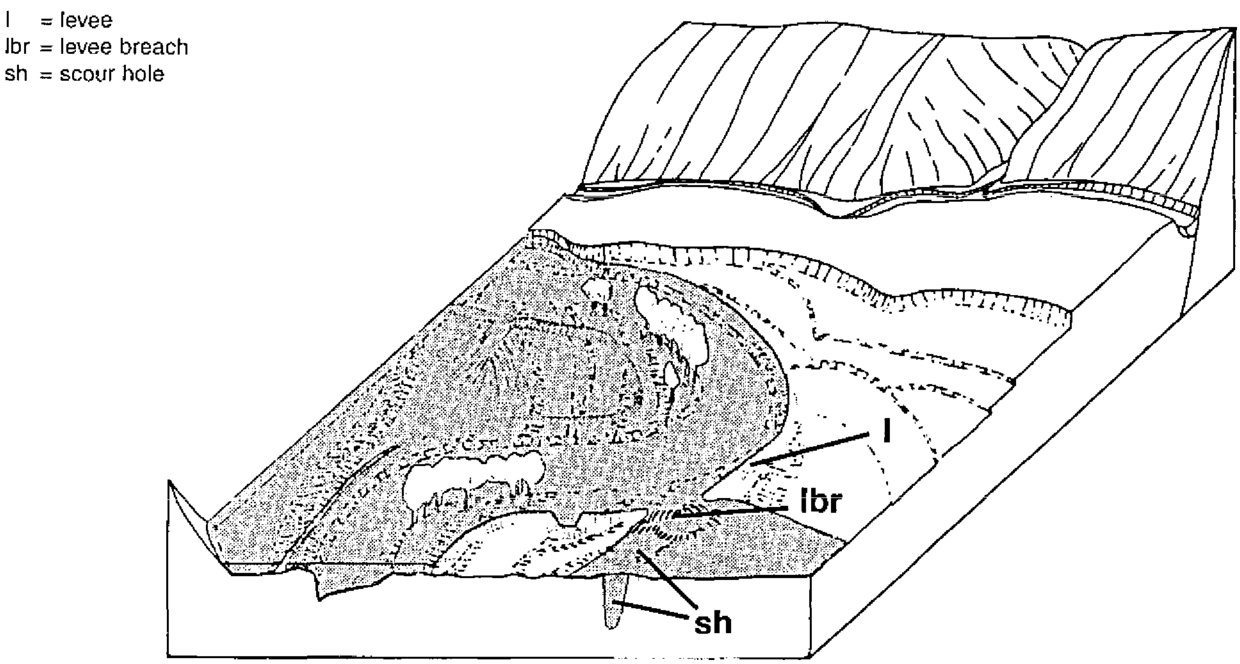


Figure 5.10. Missouri River large flood, rising stage.

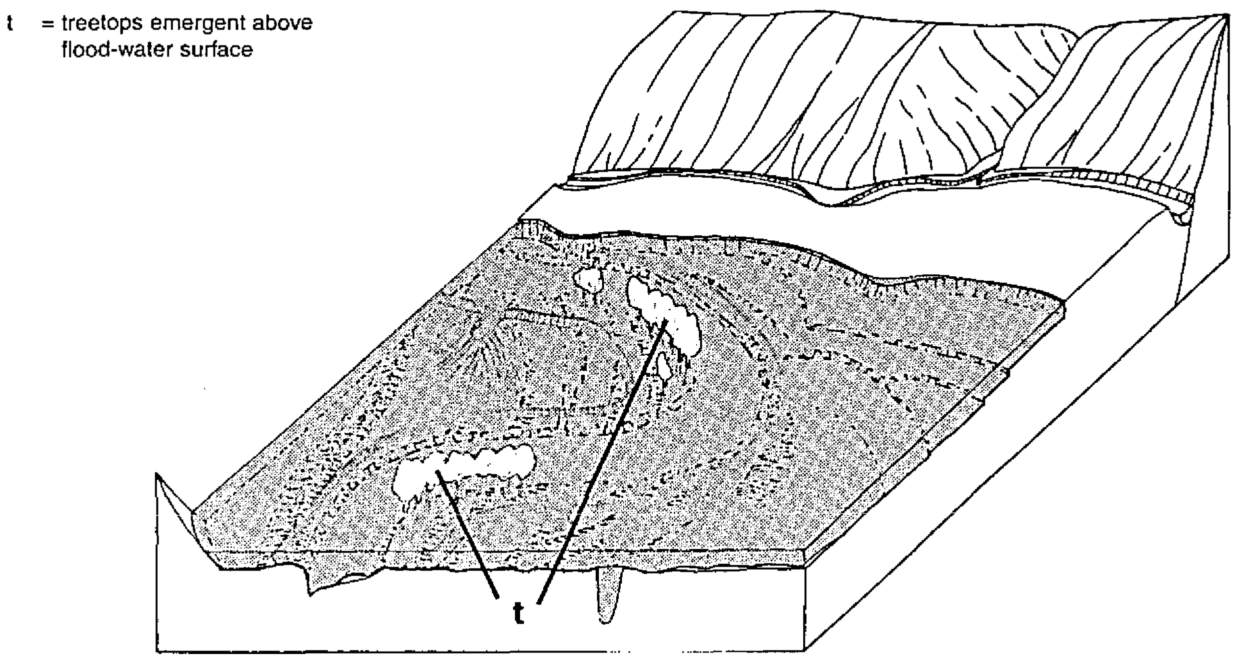


Figure 5.11. Missouri River large flood, maximum flood stage.

Chapter 6

FLOODPLAIN ECOLOGY

STATUS OF THE ENVIRONMENT

Analysis of impacts of the flood of 1993 and resulting recommendations for integrated floodplain management must be placed in the context of how the naturally functioning ecosystem has been altered by hydrologic and hydraulic modifications and changes in land cover/land use. Humans have used large rivers and their floodplains for settlement, agriculture, and commerce from prehistoric to modern times. The Mississippi, Missouri, and Illinois Rivers, like nearly all large rivers of the world, are no longer undisturbed ecosystems.

Prehistoric geography of the Mississippi River basin provided a refuge for "ancient fishes" and resulted in high biodiversity for a number of animal groups. The basin served as a primary center of diversity of North America's fish fauna. It exhibits the highest diversity of freshwater fishes for any region of the world at comparable latitudes (Robison, 1986), comprising about 260 species in 13 families, or just over 43 percent of the approximately 600 freshwater species known from North America. Ancient fishes such as jawless lampreys, sturgeons, gars, and two families with only one or two living representatives continue to survive in the basin. The bowfin, historically found in off-channel habitats and tributaries to the Missouri and Mississippi Rivers, is the only living species in the family Amiidae. For survival, it requires river backwaters and oxbows that have extensive growths of aquatic vegetation. Draining of marshes, restriction of channels by dikes and dredging, agricultural use of bottomlands, and drought have eliminated most natural pools along the lower Missouri, middle Mississippi, and their tributaries. Another example of ancient fishes in the basin is the paddlefish, which survives in the Mississippi and Missouri Rivers, and has only one living relative in China. Paddlefish survival is jeopardized by pollution, alteration of natural flows on these rivers, and dams which obstruct reproductive migrations (Dillard and others, 1986).

The Mississippi River basin's mussel fauna is an important invertebrate group and also highly diverse. Presently there are 37 living species in the upper Mississippi River. This number contrasts with only about a dozen species of freshwater mussels in all of Europe (Sparks, 1993). Most freshwater species in Europe were decimated during glacial periods. In contrast, the north-south orientation of the Mississippi provided refugia for aquatic species during harsh climatic periods.

This orientation and the extension of the Missouri into the arid west make these rivers ideal migration corridors for waterbirds (ducks, geese, swans, herons and egrets), shorebirds (e.g., sandpipers), raptors (owls, hawks and eagles), and songbirds (warblers, finches, and other birds) (Sparks, 1993). Over 50 percent of all wintering bald eagles counted in the conterminous 48 states during 1979-1982 were from these river basins (Millsap, 1986). Forty percent of North America's waterfowl and shorebirds use the Mississippi flyway to move annually between their breeding grounds in the north and their wintering areas along the Gulf Coast or South America (Smith, 1994). Floodplain forests of the Mississippi River support a rich diversity of terrestrial and wetland vertebrates. Newling (1975) reported a total of 37 amphibian, 89 reptile, 322 bird, and 71 mammal species for the Mississippi and Illinois River floodplains.

Increased human intervention in natural river-floodplain processes has influenced the ecological balance of the upper Mississippi Basin's large rivers, reducing habitat availability for many species of native flora and fauna (Fremling and others 1989; Hesse and others, 1989a; Sparks, 1992). Conversely, construction of impoundments in the Upper Mississippi River Basin has increased habitat for other species, including submergent and emergent aquatic plants (e.g., water milfoil, wild celery), lacustrine fishes (e.g., walleye, largemouth bass), and waterfowl (e.g., scaup, canvasbacks).

Human impacts on river hydrology, geomorphology, biodiversity, and ecological processes in the Upper Mississippi River Basin's floodplains have resulted in Federal and state listings of a number of species as rare, threatened, or endangered (table 6.1). The large number of rare, threatened, and endangered species near the river corridors demonstrates the importance of the Mississippi, Missouri, and Illinois Rivers to the basin's wildlife (figure 6.1, SAST Database)[1]. It must be noted that biases exist in data collection as a result of uneven sampling. However, these highly altered ecosystems no longer provide the range of aquatic habitats and riverine wetlands required by many of the species that are now in jeopardy (Smith, 1994)

Upper Mississippi River

The upper Mississippi River (source to the confluence with Missouri River) drains an area in excess of 150,000 square miles; 66 percent of the 1,106,854 acres in the upper Mississippi floodplain are used for crops and pasture land (Marler, 1993). These agricultural lands depend on

[1] The data layer plotted in figure 6.1 only shows threatened or endangered species on or near floodplains. Upland threatened and endangered species are not shown.

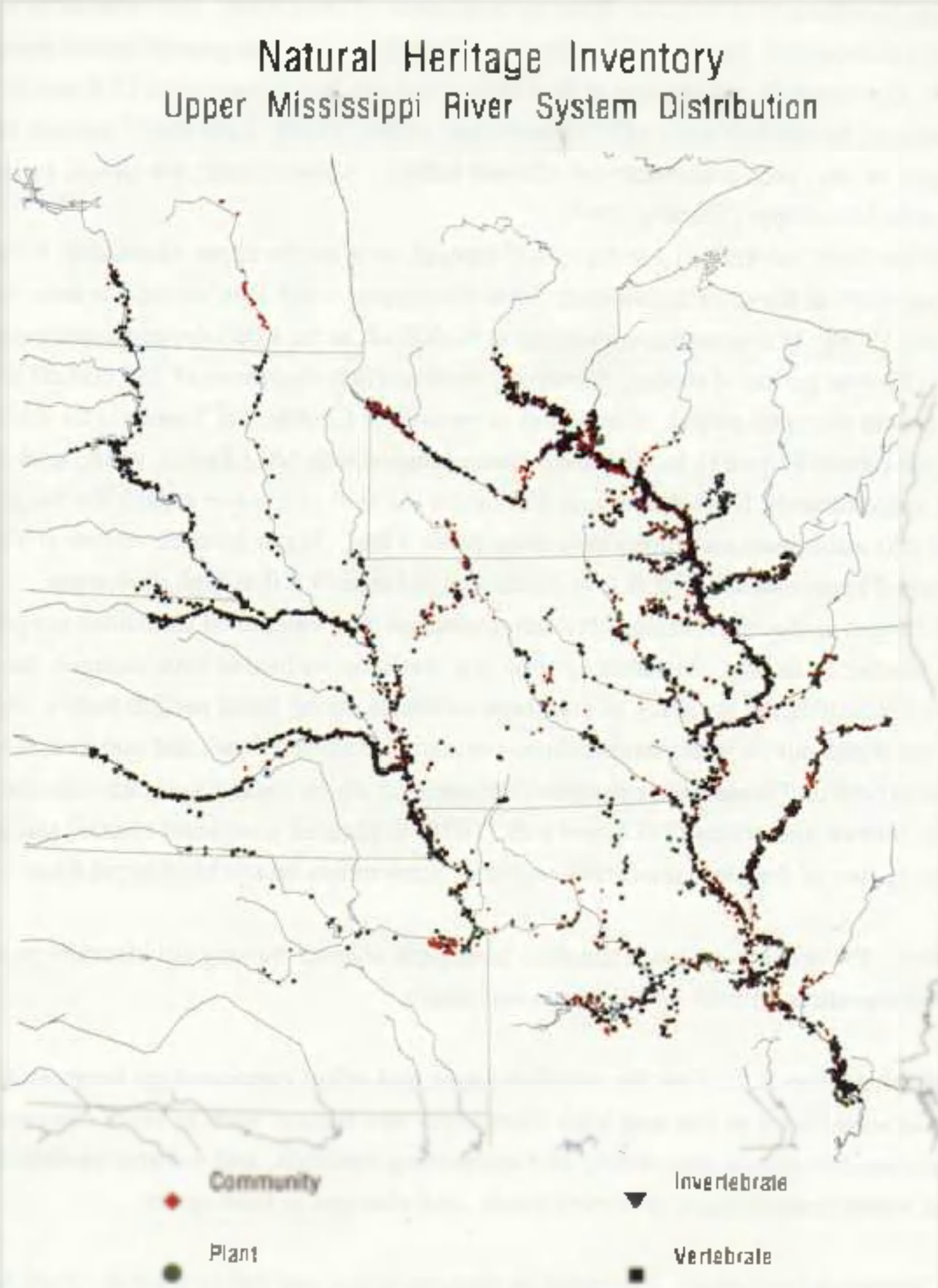
Table 6.1
Numbers of rare, threatened, and endangered species endemic to rivers of Upper Mississippi River Basin. State and Federal listings may overlap.

Taxonamic Group	Missouri River[a]		Upper Mississippi River[b]		Illinois River[b]	
	State Listed or Candidate	Federal Listed or Candidate	State Listed or Candidate	Federal Listed or Candidate	State Listed of Candidate	Federal Listed or Candidate
Plants	7	7	164	11	43	8
Insects	0	6	14	1	6	3
Mussels	0	2	20	7	0	0
Fish	16	10	22	4	3	0
Amphibians	0	0	4	1	1	1
Reptiles	2	4	20	4	4	3
Birds	4	14	30	4	10	3
Mammals	3	3	12	4	2	1
TOTAL	33	45	286	36	69	19

[a]Whitmore, S.B. and Keenlyne, D.G., 1990.
[b]The Natural Heritage Network and The Nature Conservancy, MRO (H. Watson, personal commun., 1994)

an extensive levee system for protection against flooding. Theiling (1994) reported that the upper floodplain reach (UMR navigation Pools 1-13) has the least disturbed floodplain habitat because of the presence of the Upper Mississippi River Fish and Wildlife Refuge. From the Chippewa River in Wisconsin to the Rock River in Illinois, the Upper Mississippi River National Fish and Wildlife Refuge totals approximately 200,000 acres. Downstream, the Mark Twain National Wildlife Refuge includes 28,000 acres which are directly managed by the U.S. Fish and Wildlife Service. Aquatic habitats, however, have been influenced by impoundment, sedimentation, and low-flow water regulation. Compared to habitat on the upper portion of the upper Mississippi River, aquatic habitat on the lower floodplain reach (UMR navigation Pools 14-26) has been more

Figure 6.1 Rare or endangered species and their observed occurrences in or near the upper Mississippi, lower Missouri and Illinois Rivers and their tributaries (The Nature Conservancy Natural Heritage Inventory and SAST Database).


Natural Heritage Inventory
Upper Mississippi River System Distribution
Community
Invertebrate
Plant
Vertebrate

affected by hydrologic perturbations, sedimentation, and conversion of floodplain habitats to agriculture. This reach also has few public lands which are widely separated. The middle Mississippi (confluence of Missouri River to confluence of Ohio River, also referred to as the open river) is unpooled, lined along bendways with rock rip-rap, and greatly incised throughout its length. For example, the channel at St. Louis, Missouri, has downgraded 12 ft and its width has constricted by one half since 1837 (Simons and others, 1974). Less than 5 percent of the total aquatic area in this reach is currently off-channel habitat. Aquatic plants are almost entirely absent in the middle Mississippi (Theiling 1994).

Water level elevations have decreased through time on the upper Mississippi River at low discharges, while at the same locations at flood discharges, water level elevations have increased (Wlosinski, 1994). Water surface elevations at 60,000 cfs at St. Louis dropped approximately 8 ft over the 133-year period of record. However, water surface elevations at 780,000 cfs have risen about 9 ft over the same period. The period of record for Chester and Thebes is far shorter than at St. Louis (about 55 years), but the same relationship is seen. At Chester, water level elevations dropped approximately 1.5 ft during low discharges (60,000 cfs), while at high discharges (780,000 cfs) water level elevations have risen about 5 feet. Water level elevations at Thebes have dropped approximately 5 ft at low discharges and risen 3.5 ft at high discharges.

Changes in the relationships between discharges and water level elevations are probably due to a number of factors. Methods of obtaining discharge estimates have changed, leading to questions concerning the accuracy of discharge estimates during flood periods before 1933. Natural variations due to water temperature, vegetation, sediment load, and conversion from forests to agricultural areas have influenced the speed at which water travels through the system. However, Simons and others (1974) and Belt (1975) implicated levees and channel training structures as two of the more important causes of these trends on the Mississippi River.

Conclusion: Preliminary evidence suggests levees and channel training structures have influenced water level elevations at both low and high discharges.

Recommendation 6.1: Test for possible cause and effect relationships between observed changes in water level at low and high discharges and factors such as river channel-floodplain modifications, measuring and estimating methods, and natural variation due to different water temperature, sediment loads, and changes in land cover.

Changes in biodiversity are related to changes in land use and land cover. Pool 8, located at LaCrosse, Wisconsin, represents an area on the upper Mississippi River which is considered to be highly productive. Between 1891 and 1989, open water increased from 21 percent to 42 percent; aquatic vegetation increased from 2 percent to 20 percent; grasses/forbs decreased from 43 percent to 10 percent; woody terrestrial vegetation decreased from 48 percent to 17 percent; agriculture decreased from 5 percent to less than 1 percent; urban/developed land increased from 2 percent to 10 percent; and sand/mud decreased from 2 percent to less than 1/2 percent (Yin and Nelson, 1994). Nearly 80 percent of the island habitat in lower Pool 8 was lost between 1939 and 1989 (Yin and Nelson, 1994). The increase in open water and aquatic vegetation and decrease in island habitat are related to construction of lock and dam 8. The reduction in woody terrestrial vegetation is also partially related to the navigation project. Large tracts which would be inundated by the damming of the river were cleared of trees prior to flooding.

Figure 6.2 illustrates changes which have occurred between 1891 and 1989 for Pool 26 (St. Louis, Missouri area). Over the 98-year period, water increased from 15,507 acres to 17,445 acres; marsh increased from 55 acres to over 1,000 acres; grasses/forbs decreased from over 5,000 acres to just under 2,000 acres; woody terrestrial vegetation decreased from 18,000 acres to just under 16,000 acres; sand/mud decreased from 2,300 acres to 200 acres; agriculture increased from 17,400 acres to 20,000 acres, and urban/developed increased from 350 acres to 2,700 acres (Yin and Nelson, 1994). Increases in open water and marsh and decreases in sand/mud are related to the construction of lock and dam 26 in the 1930's.

The St. Louis, Missouri, quadrangle provides a base for plotting important ecological information along the upper Mississippi River (figure 6.3), including mussel beds, heron rookeries, and bald eagle wintering sites. These areas provide needed habitat and represent the few remaining areas which reflect the naturally functioning ecosystem in that stretch of the river.

Unlike Pool 26 which was created by the construction of the lock and dam, the open river of the middle Mississippi below lock and dam 27 is free flowing. Figure 6.4 illustrates historic changes which have occurred for an open river reach at Cape Girardeau, Missouri. Between 1891 and 1989, open water decreased from 16,800 to 12,100 acres; marsh increased from 0 acres to 15 acres; grasses/forbs decreased from 2,900 to 2,400 acres; woody terrestrial vegetation decreased from about 21,700 to 13,500 acres; sand/mud decreased from about 4,400 to 840 acres; agriculture increased from 23,000 to 38,700 acres, and urban/developed increased from 40 to 1,400 acres.

Lower Missouri River

All 750 miles of the Missouri River below Sioux City, Iowa, have been channelized or stabilized for navigation and subsequent agricultural development of floodplain lands. Dikes and revetments have narrowed the formerly braided channel and floodplain from an average width of five miles (Hesse, 1989a) to a single channel under 1,000 feet (Schmulbach and others, 1992). Channel narrowing by construction of training structures and sediment reduction from

Figure 6.2 Changes in land cover/land use between 1891 and 1989 for an impounded reach of the upper Mississippi River at Pool 26 near Alton, IL. Changes were less than $\pm$ 5.5 percent at Pool 26 for all categories and open water increased 4 percent over the 98 year interval. (Yin and Nelson 1994, EMTC-SAST Database)

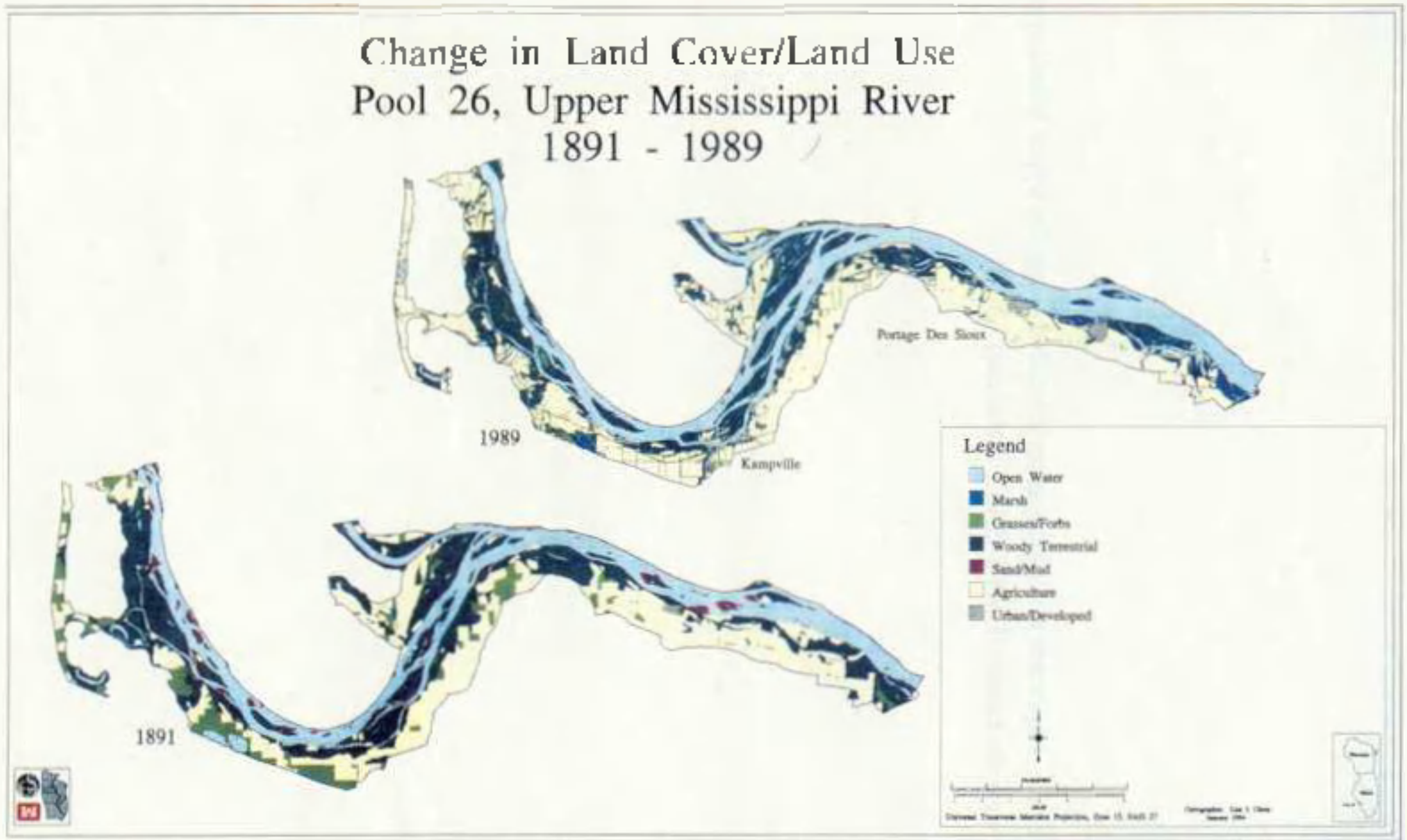

Change in Land Cover/Land Use
Pool 26, Upper Mississippi River
1891 - 1989
Portage Des Sioux
1989
Kampville
1891
Legend
Open Water
Marsh
Grasses/Forbs
Woody Terrestrial
Sand/Mud
Agriculture
Urban/Developed

Figure 6.3 Important ecological areas identified along the upper Mississippi River near St. Louis. (EMTC-SAST Database)

Mississippi River

Significant Biological Habitat

Portion of Saint Louis 100k USGS Quad

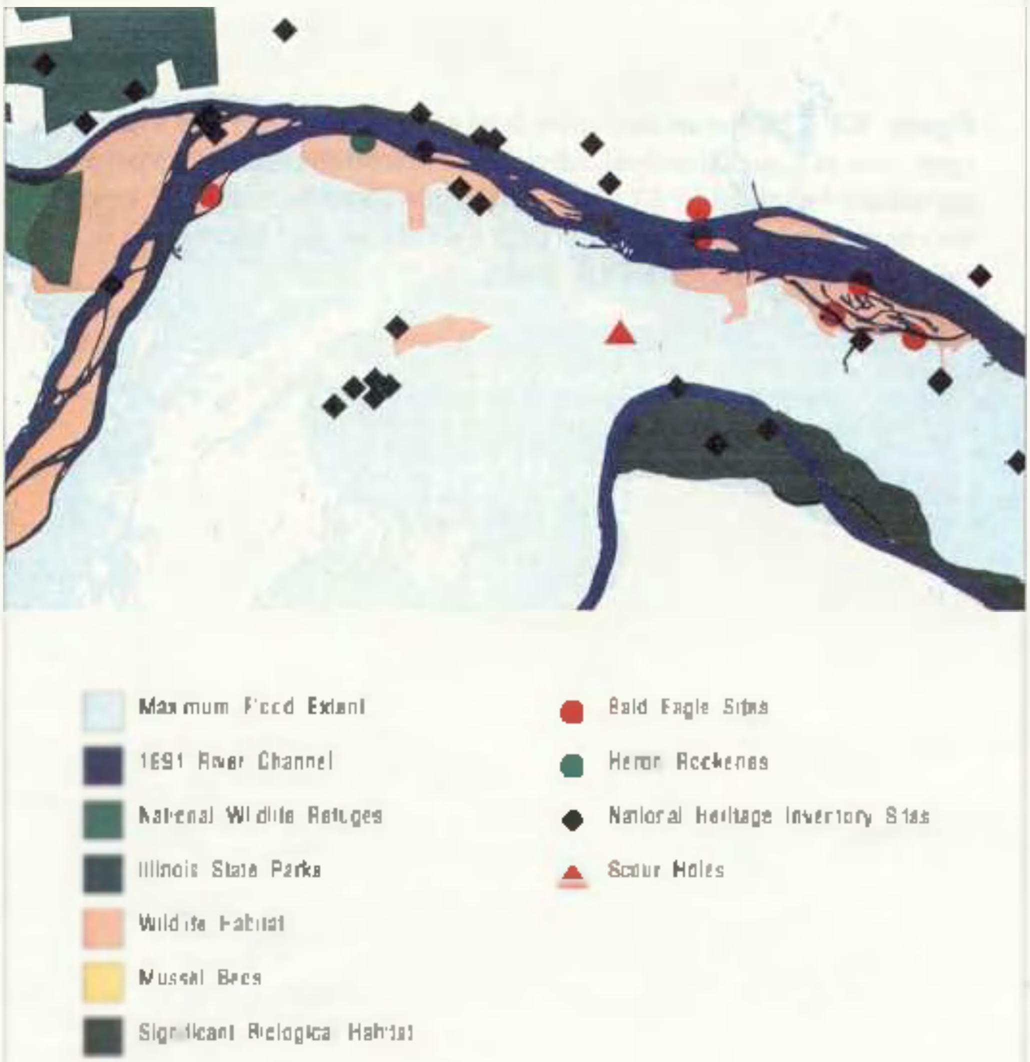
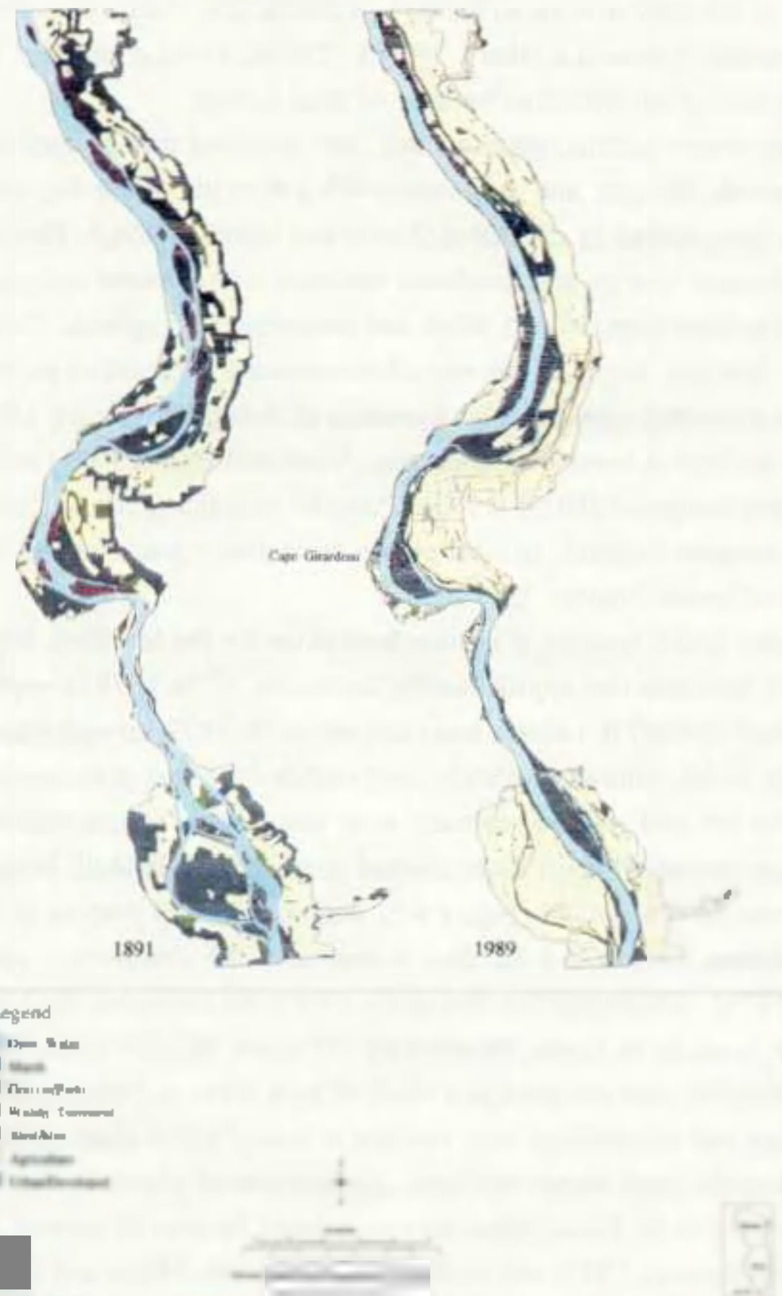


Figure 6.4 Changes in land cover/land use between 1891 and 1989 for an open river at Cape Girardeau, Missouri. Forest decreased by 12 percent, agriculture increased by 23 percent and open water decreased by 7 percent in the channelized Cape Girardeau reach over the 98 year interval. (Yin and Nelson 1994, EMTC-SAST Database)

Change in Land Cover/Land Use
Open River, Upper Mississippi River
1891 - 1989



impoundments have reduced river turbidity and caused bed degradation. Nearly a fourfold decline in turbidity has been observed in the Missouri River at St. Louis since 1930 (Pfleiger and Grace, 1987) and the river's elevation downstream from Gavins Point Dam has downcut 10.3 ft between 1929 and 1980 (Hesse and others, 1989a). Reductions in turbidity has been associated with shifts in the composition of Missouri River fishes (Pflieger and Grace, 1987) and bed degradation has led to perching of tributary streams so that at low discharges, stream channels are drained, preventing fish access (Hesse and others, 1989a). The increased gradient of perched tributaries also leads to the loss of infrastructure because of head cutting.

Important macro and microhabitats that once provided mid-channel sandbars, timbered islands, side channels, sloughs, and backwaters with a diversity of depths, velocities, and substrates, have been altered or eliminated (Hesse and others, 1989a,b; Hesse, 1994; Galat and others, 1994). Former riverine and floodplain wetlands with seasonal hydrologic connections to the Missouri River have been drained, filled, and converted to croplands. Snag removal has reduced habitat diversity, increased the rate of downstream transport of particulate organic matter which played an important role in trophic dynamics of the system (Hesse, 1994), and has been associated with declines in benthic invertebrates (Mestl and Hesse, 1993) and the physiological condition of native sturgeons (Hesse, 1994). Past and continuing construction of levees has further isolated remnant habitats. In most places, remaining riparian habitat is confined to narrow strips riverward of levees (Marler, 1993).

Preliminary SAST analysis of historic land cover for the Marshall, Missouri, 1:100,000-scale quadrangle, indicates that approximately 76 percent of the 1879 floodplain examined (60 percent of the bluff-to-bluff floodplain was analyzed in the 1879 survey) was natural habitat, including forests, brush, willows, wetlands, sand islands-bars, and grasslands. The categories brush, sand island-bar, and willows represent early successional stages related to periodic flooding. Comparison of Missouri River channel geometry at Marshall, Missouri quadrangle (RM 242-325), between 1897 and 1972 (Figure 6.5) illustrates that 29 percent of the river surface area of this reach has been lost due to reductions in channel width, complexity, and sinuosity (Funk and Robinson, 1974). Channelization during the 1900's has shortened the Missouri River channel from Sioux City, Iowa to St. Louis, Missouri by 127 miles; 552,000 acres (83 percent) of the channel and its erosion zone are gone as a result of rock dikes and earthen levees. Changes in channel hydrology and morphology have resulted in loss of active channel habitats such as oxbows, side channels, sand islands and bars. Surface area of islands in the lower Missouri River from Rulo, Nebraska to St. Louis, Missouri was reduced by over 90 percent between 1879 and 1954 (Funk and Robinson, 1974) and sandbars by 97 percent (Hesse and others, 1988). This habitat is critical for Federally listed least terns and piping plovers (Smith, 1994). It is also important to native invertebrates and fishes. Forty-six species, or two-thirds of the total lower

Missouri fish fauna, use sand island-bar habitats (Grace, 1985). Sand island and bar habitats are dynamic. Recently deposited and exposed sandbars are rapidly colonized by willows and succeeded by cottonwoods which dominate the canopy for up to 30 years (Bragg and Tatschl, 1977).

Ninety-five percent, or more than 1.8 million acres, of native vegetation has been replaced by row crop agriculture along the lower Missouri River. In addition, over 1 million acres of tributary valley lands have been inundated by 75 Federal dams on 53 tributary streams. In all, nearly 4.4 million acres of river channel, backwater, riparian wetland, timber and grassland have been altered (Hesse and others, 1988).

Little land is managed today for natural resource benefits along the lower Missouri River compared to the upper Mississippi River. Approximately 15,000 acres are included in two National Wildlife Refuges: DeSoto and Squaw Creek. Missouri administers about 23,000 acres of floodplain and 31 miles of Missouri and Mississippi River frontage as Conservation Areas (J. Robinson, 1990; T. Grace, Missouri Department of Conservation, personal commun., 1994).

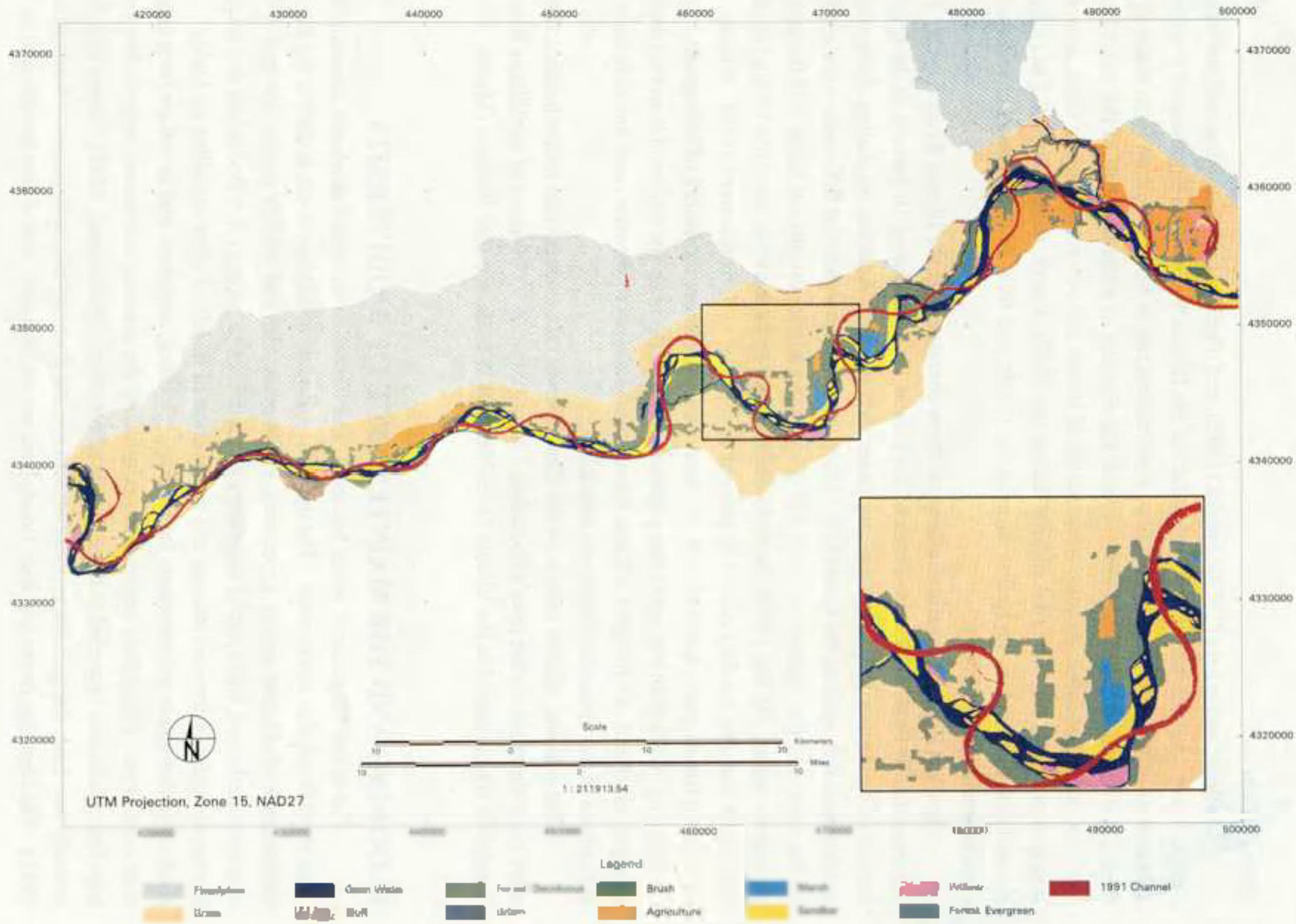
An analysis relating river water elevations at high and low discharges over time, similar to that conducted by the National Biological Survey for the upper Mississippi, has been requested by the SAST for the lower Missouri River at Hermann, Waverly, and St. Joseph, Missouri. Preliminary results indicate an increase in water level elevation at flood discharges over the period of record for all sites. However, no relation between water level elevation over time at low discharges is evident at present (Wlosinski and Olson, 1994).

Hydraulic model simulations for the lower Missouri in the reach below Gavins Point (Latka and others, 1993) indicate that 98 percent of the channel in late summer and autumn was less than 3 ft deep during median flow conditions before regulation and 87 percent after regulation. Velocity distributions also shifted under the regulated condition. Velocities between 0.15 and 0.76 m/s occur less frequently under regulation, while velocities between 0.76 and 1.22 m/s occur more frequently. These differences in depth and velocity frequencies resulted from training structures and flow regulation that occur in support of navigation along the lower Missouri River. Such changes have altered microhabitats for native fish communities adapted to shallower depths and slower water velocities.

Recommendation 6.2: Expand depth and velocity hydraulic model simulations to the entire lower Missouri River and determine whether or not river flow regulation has also affected seasonal hydrographic, temperature, and turbidity patterns.

Figure 6.5 Changes in lower Missouri River channel surface geometry between 1879 and 1986 for the Marshall, Missouri quadrangle. Preliminary analysis indicates the area of unconnected islands was reduced by over 95 percent and water surface area was reduced by about 30 percent over the 107 years. Land cover/land use categories for this early settlement period illustrate a diverse floodplain plant community dominated by grasslands, deciduous forests and sand bars. Restoration and flood management strategies for upper Mississippi Rivers should strive to recreate a representation of this historic channel pattern and plant community. (SAST Database)

MARSHALL QUADRANGLE: 1879 LAND COVER AND 1991 CHANNEL



Illinois River

Bellrose and others (1979), Sparks (1992), and Theiling (1994) summarized use of the Illinois River. Aquatic and terrestrial habitats of the Illinois Valley have experienced a series of alterations to the system since 1900: first, a permanent rise in water elevation from water diverted from Lake Michigan (Theiling 1994); second, the draining of more than half of the 161,878 ha (400,000 acre) floodplain through construction of levees and pumping stations; third, an upsurge in untreated urban and industrial effluent during the 1920's; fourth, creation of a 2.7 m (9 ft) channel and its attendant navigation dams in the 1930's; and fifth, an acceleration in sedimentation rates beginning in the 1940's.

Sparks (1992) summarized effects of these alterations on the Illinois River fishery. He reported that in 1908, a 200-mile reach of the Illinois River produced 10 percent of the total U.S. harvest of freshwater fish--more than any other river in North America (excluding rivers with anadromous fish, such as the Columbia). More than 2,000 commercial fishermen were employed on the river, and the commercial yield was 24 million pounds annually, or about 178 lbs/acre of permanent water. By the 1950's the yield had dropped to 38 lbs/acre; since the 1970's the yield has been 4 lbs/acre, totaling only 0.32 percent of the total U.S. freshwater harvest. Similar downward trends were recorded over the same period for other indicators of biological productivity: waterfowl and sport fish populations. The declines are attributable to two major changes: diversion of Chicago's effluent from Lake Michigan to the river, and intensification of agriculture in the upland drainage and floodplain.

One national wildlife refuge on the Illinois River retains important native habitats that were once abundant on the river's floodplain. Approximately 9,000 acres of the Illinois River floodplain are contained in the Illinois River National Wildlife and Fish Refuges (Marler, 1993).

FLOODING AND THE MAINTENANCE OF BIODIVERSITY

The upper Mississippi, lower Missouri, and Illinois Rivers share attributes common to all large river-floodplain ecosystems. The dynamic nature of floodplain rivers is critical for the maintenance of efficient energy processing, biodiversity, fish and wildlife production and migration pathways, transport of sediments and nutrients to support rich floodplain and estuary resources, and conveyance, storage and moderation of floods. Fishes capitalize on highly productive floodplain environments for feeding, spawning, nurseries, and as refuge from adverse river conditions. Floodplain wetlands are considered the essential component responsible for the high fish production recorded in large, low gradient rivers (Welcomme, 1985). Areas that flood annually also have the greatest production and species diversity of plants (Gosselink and others, 1981). The idea that rivers and their floodplains are so intimately linked that they should be understood, managed, and restored as integral parts of a single system is the cornerstone of floodplain restoration and integrated floodplain management (National Research Council, 1992).

Periodic flooding is a characteristic hydrologic feature of large river-floodplain ecosystems. Floods connect the river channel to its adjacent floodplain. This idea is expressed as the "Flood Pulse Concept", whereby pulsing of river discharge is the major force responsible for maintaining the complex physical structure, rich biodiversity, and plant and animal productivity associated with large floodplain rivers (Junk and others, 1989).

The flood of 1993 had an exceptional effect on the floodplain ecosystems. Infrequent large flood disturbances are necessary to reset the dynamic functioning of rivers. Some habitats, like patches of mature floodplain forest, are destroyed, while other habitats, like sand islands, are created. Many individual animals succumb, but populations of others surge, such as annual plants and wetland spawning fishes. For example, airborne surveys in autumn 1993 found that waterfowl were abnormally scarce on the floodplain. The peak number of ducks was down 58 percent in the Illinois valley and 80 percent in the upper Mississippi valley (Havera in Tenenbaum, 1994). See pages 6-12 and 6-13 for examples where the flood of 1993 enhanced fish and wildlife. At Marshall, Missouri, Landsat Thematic Mapper (TM) before (September 29, 1991) and after (October 4, 1993) the 1993 flood data acquired by the SAST indicate that approximately 173,150 acres (70,100 ha, or 63 percent) of the Missouri River floodplain were impacted. About 6,400 acres (2600 ha) of pre-flood wetlands were affected by sand deposition. However, the post-flood TM scene indicates that an additional 46, 300 acres (18,750 ha) of water were on the Missouri River floodplain (SAST database).

Conclusion: Analysis of a small area of the lower Missouri River impacted by the flood of 1993 indicates creation of a large new area of various wetland types.

Recommendation 6.3: Identify the types and analyze the distribution, acreage, and ecology of floodplain wetlands created, destroyed, or modified by the flood of 1993. Newly created wetlands should be reexamined periodically by remote and ground surveys over the next decade to document their morphometric changes, longevity, and ecological value.

Recurrent smaller magnitude flood pulses are as important as the rare large flood event. These more frequent pulses provide a predictable reconnection between the river and its floodplain, permit energy and nutrient exchange, and provide access to critical habitat. Not only is periodic flooding important to a functioning river-floodplain ecosystem, but seasonal low water periods and periodic droughts are also essential to maintain the dynamic equilibrium of rivers in the Upper Mississippi Basin because different plant and animal communities benefit from the habitats and resources made available at these times.

Timing and duration of the flood pulse are critical to fishes that gain access to the floodplain for feeding and spawning. Ideal conditions for spring spawning fishes occur during years in which the flood and temperature rise are coupled. Figure 6.6 illustrates this coupling of temperature and flood pulse (Junk and others, 1989). So important is the annual rise of temperature and discharge, that the amount by which fish yield per unit water area is increased by predictable flood pulse has been termed the "Flood-Pulse Advantage" (Bayley, 1991). The lower Missouri River was reconnected to its floodplain for four months in spring and summer 1993. Spring temperature rise was more strongly coupled with rising river stage during this period of reconnection than any rise observed over the preceding decade (Gelwicks, 1994).

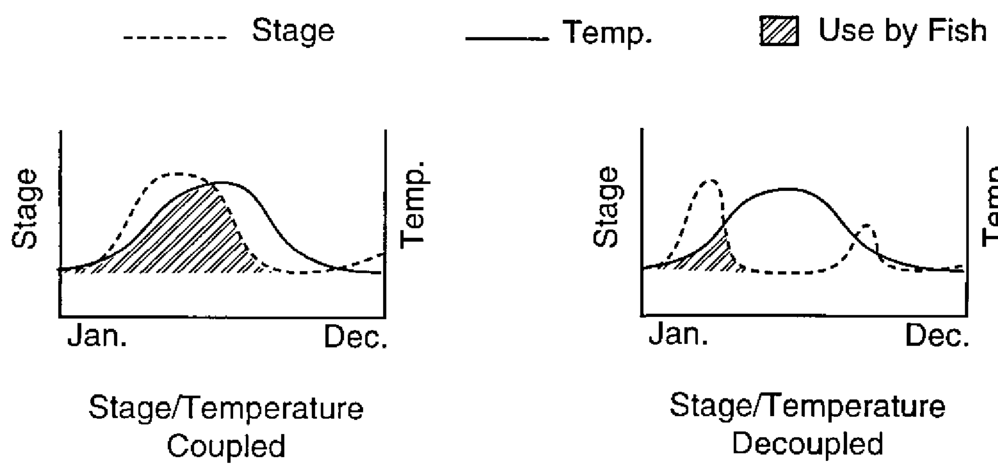


Figure 6.6 Large floodplain ecosystems like the upper Mississippi, lower Missouri and Illinois Rivers are created and maintained by periodic flooding. Ideal conditions occur for spring-summer floodplain spawning fishes in upper Mississippi basin rivers to reproduce in years where the floodpulse and temperature rise are coupled (left); conversely, recruitment is poor if the flood retreats too soon during the warm growing season (right). (Junk et al. 1989)

Conclusion: Evidence thus far indicates that the magnitude and timing of the 1993 flood provided appropriate temperature and discharge cues for spawning river-floodplain fishes.

Recommendation 6.4: Further examine historic temperature and river stage records to evaluate the temperature-river stage coupling relationship for the Mississippi, Missouri, and Illinois Rivers.

Timing and severity of changes in water levels are also important to floodplain productivity. Prior to modification of the natural hydrograph, changes in water levels were fairly gradual and flooding lasted longer. Now, water level changes are more abrupt, with sharper increases and decreases, and floods last for shorter periods of time (Bayley, 1991). These conditions are detrimental to floodplain productivity and the exchange of energy and nutrients between the floodplain and river channel (Hesse and others, 1988, 1989b).

Modification of the natural flood pulse on the lower Missouri River can be attributed to operation of mainstem reservoir releases to maintain adequate summer flows for navigation and other system purposes, such as flood control and water supply. These minimum and full service target flows are provided for the originally projected twelve million tons of river transport per year (General Accounting Office, 1992). The commercial portion of total navigation peaked in 1977 with shipments reaching about 3.3 million tons and has generally declined since then (USACEb, 1993). Total tonnage actually transported averaged 6.7 million tons between 1984 and 1988. Approximately 2.5 million tons (37 percent) of that amount was transport of commercial materials like farm products, chemicals, petroleum products, and metals that require navigation flows for movement. About 0.33 million tons (5 percent) of waterways improvement materials (primarily rock) also required navigation flows for transport. The remaining 3.8 million tons (57 percent) of materials transported on average during this period were mined sand and gravel; to a large extent, the transport is a riverbed to bank movement of 1 to 2 miles (USACEb, 1993). Regardless of the total tonage shipped, a minimum flow is necessary if any shipping is to occur. If a flow regime conducive to aquatic habitat restoration is to be reintstated while flows for navigation are maintained, these flow regimes must be coordinated.

Sampling since the flood of 1993 illustrates how quickly fish and wildlife responded to reconnection of the river and its floodplain. Peterson (1994) provided evidence which suggests that the flood may have affected fish distribution and relative abundance in the lower Mississippi River. For example, high numbers of young-of-the-year white bass (844/net day) and black crappie (6,500/net day) were captured in fyke nets. In one 24-hour set, 8,600 mostly young-of-the-year fish, weighing 400 pounds and representing 22 species, were collected. To put these numbers in perspective, that single catch represented 50 percent of the total 1992 catch. Several young-of-the-year blue suckers (a candidate species for Federal listing) were also collected and may represent the first documented evidence of blue sucker reproduction in the middle Mississippi River (Hrabik, 1994). Blue sucker and black crappie are uncommon in the open river. Since 1991, only five adult blue suckers have been captured by Open River Field Station biologists. Prior to recent large catches, only 54 black crappies were captured in the open river since 1991.

Maher and Theiling (1994) investigated movements of riverine fishes on to flooded terrestrial habitats associated with extended flooding during spring and summer 1993. Fish communities were sampled at three separate areas of the lower Illinois River floodplain. Each area contained four separate habitat types: a floodplain depression lake adjacent to the main channel, a forested area around the lake, an open area outside the forested area which was primarily agricultural, and the shoreline as the flood waters rose and receded. A total of 52 species was collected in the three study areas. Fish density and species richness were highest in shoreline habitats. Catch rates were highest in the shoreline habitats for bluegill, followed by gizzard shad, black crappie, golden shiner, and largemouth bass. Common carp was the most abundant species in all other habitats. Channel catfish catch rates were highest in forested areas. The duration of the flood allowed nest building sunfishes enough time to successfully spawn. This was reflected in high catches of young-of-the-year largemouth bass, black crappie, and bluegill.

Post-flood sampling of flood-created scour areas connected to the lower Missouri River showed that they also contained a high abundance and diversity of fishes (J. W. Robinson, Missouri Department of Conservation, unpublished data, 1994). About one fish per minute of electrofishing was collected during a midwinter 1994 sample, and one night of gill netting in March 1994 recovered 14 fish species, including important recreational, commercial, and native taxa (e.g.,black and white crappies, channel catfish, buffalo, carpsuckers, shovelnose sturgeon, and reproductively mature sauger). Birds are also using these newly created wetland habitats. Avian use surveys conducted by helicopter during April-May 1994 on flood-scoured connected, nonconnected and seasonally flooded (ephemeral) wetlands in the lower Missouri River floodplain, Missouri, recorded about 2,000 individual birds representing 33 species at 59 sites. About 50 percent of the total birds observed were using seasonally flooded wetlands (D. Humburg, Missouri Department of Conservation; D. Helmers, Soil Conservation Service, unpublished data). High resolution digital elevation models are needed to adequately study and monitor these types of shallow habitat.

Conclusion: Preliminary evidence indicates that the flood of 1993 provided significant ecological benefits to river-floodplain fish and wildlife resources.

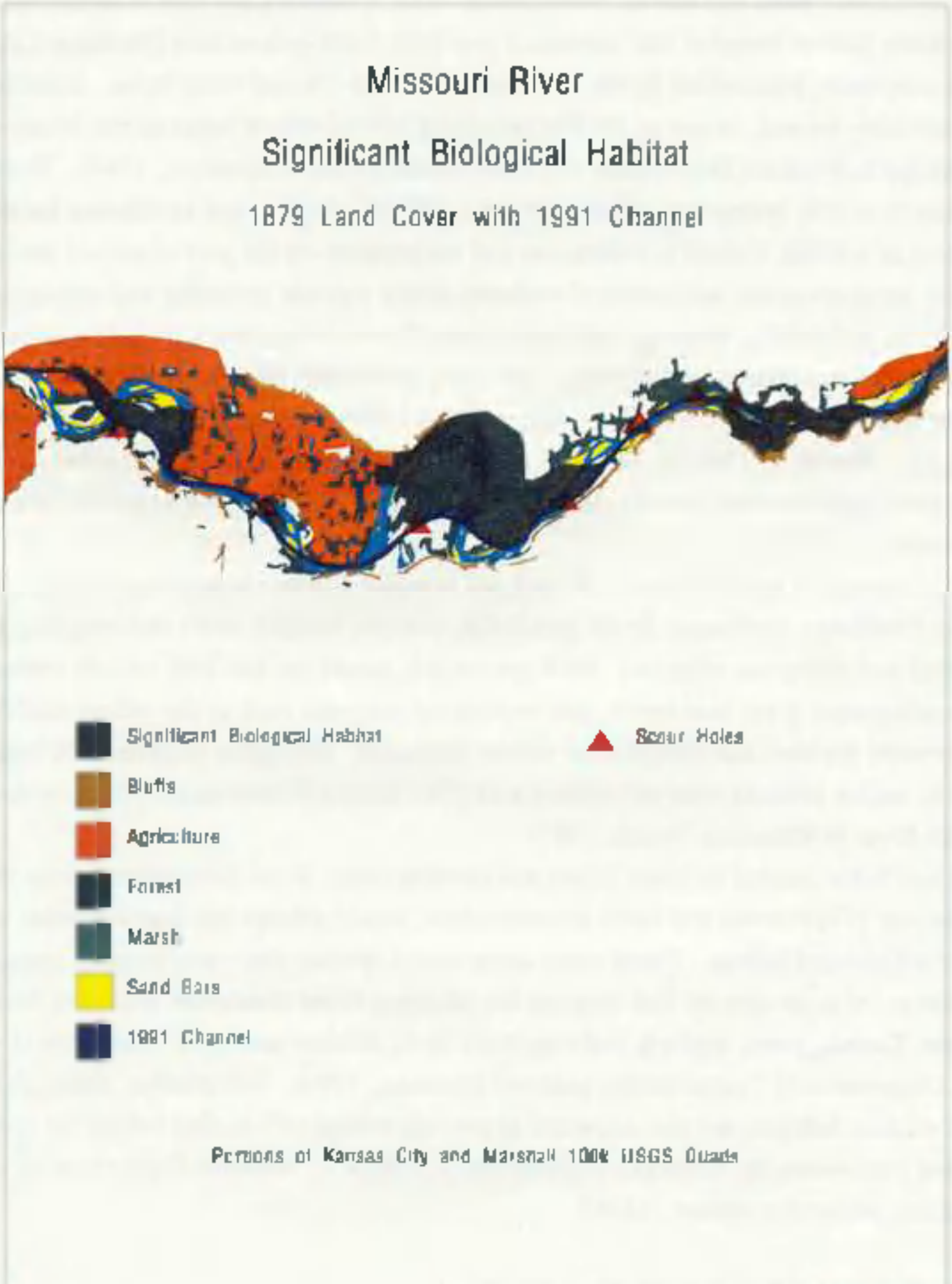
Recommendation 6.5: Resource agencies should capitalize on the opportunity provided by the flood of 1993 to further evaluate use of newly-created aquatic and wetland habitats by a diversity of river-floodplain plant and animal communities. This information should be used to identify the habitats that offer the greatest potential acquisition benefits for restoration programs.

OPPORTUNITIES TO RESTORE RIVER-FLOODPLAIN BIODIVERSITY AND ECOLOGICAL INTEGRITY

The upper Mississippi, lower Missouri, and Illinois Rivers experienced extensive damage to training structures and levee systems because of the 1993 flood. Some areas were so damaged that there is uncertainty as to whether these lands can, or should, be restored to pre-flood conditions. Because of these damages and uncertainty about restoring the area, there is an excellent opportunity to develop an integrated hydrologic, hydraulic, geomorphic, economic, and ecologic approach to evaluate these damaged areas with respect to existing and future human and environmental needs. Success of any long-term management strategy incorporating biodiversity enhancement for the upper Mississippi River-floodplain ecosystem depends on landowner support and coordination with state and Federal agencies. The Partnership for Missouri Riverlands is an example of such a program (Missouri Department of Conservation, May 27, 1994). It calls for buying 12,000 acres of flood-damaged land from willing sellers in 25 counties along the lower Missouri River and, obtaining easements on an estimated 20,000 acres through the Emergency Wetland Reserve Program. Priority will be given to purchasing land which can be restored, without adversely affective neighbors, to the historic floodway by leaving it open to flooding. The proposal brings together expertise from Federal government organizations (U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, Soil Conservation Service, Agricultural Stabilization and Conservation Service), state organizations (Missouri Department of Conservation) and nongovernment organizations (Ducks Unlimited, National Wild Turkey Federation, Quail Unlimited, The Nature Conservancy), and private landowners. Plans by the U.S. Fish and Wildlife Service include creation of a new 6,000 acre refuge - Big Muddy National Fish & Wildlife Refuge. This partnership will benefit native plant and animal communities and nine Federally-listed endangered species. Recreational opportunities provided under the plan will include nature study, wildlife watching, hiking, nature photography, hunting, and fishing.

An area on the lower Missouri River located in the Kansas City and Marshall quadrangles illustrates an opportunity for developing an integrated plan on the Missouri River for restoration, maintenance, and enhancement of biodiversity. Figure 6.7 shows an example of ecologically important areas overlaid on the 1879 historic floodplain. These areas represent historic oxbows,

Figure 6.7 Important ecological areas identified along the lower Missouri River near Kansas City.(EMTC-SAST Database)


Missouri River
Significant Biological Habitat
1879 Land Cover with 1991 Channel
Significant Biological Habitat
Scour Holes
Bluffs
Agriculture
Forest
Marsh
Sand Bars
1991 Channel
Portions of Kansas City and Marshall 100k USGS Quads

wetlands, and backwater areas that are essential habitat for river-floodplain fishes, avian species, and their associated plant and animal communities. The Sunshine Lake area is an example of a Missouri River habitat complex that contains a pre-1993 flood oxbow lake (Sunshine Lake), wetlands, croplands, bottomland forest, sandbars, and flood-created scour holes. Sunshine Lake, which is privately owned, is one of the few remaining natural oxbow lakes on the Missouri River (W. Dieffenbach, Missouri Department of Conservation, personal commun., 1994). There is an opportunity to modify levees that failed during the 1993 flood event and to enhance habitat for a wide variety of wildlife, if there is willingness and cooperation on the part of private land owners. Permanent, semipermanent, and seasonal wetlands would provide spawning and rearing areas for riverine fishes, and nesting, feeding, and resting areas for migratory birds, including waterfowl. Restored bottomland forests would provide perching and resting sites for bald eagles, herons, and egrets, while also increasing cover for a wide variety of mammals and resident birds. Sandbars would provide rearing and feeding areas for endemic mainstem riverine fishes, including candidates for Federal listing such as sturgeon and sicklefin chubs, as well as feeding areas for wading birds.

Additional fish species that would find this complex suitable habitat are buffalo, channel and flathead catfishes, freshwater drum, paddlefish, crappie, bluegill, short and longnose gar, gizzard shad and numerous minnows. Bird species that would use this area include mallard, wood duck, Canada goose, great blue heron, and neotropical migrants such as the yellow warbler, yellow-throated warbler, and possibly the willow flycatcher. Biologists recorded 150 bird species that utilized such a restored riverine wetland area (Ted Shanks Conservation Area) on the upper Mississippi River in Misssouri (Smith, 1987)

Scour holes created by levee failure and riverine scour, if not disconnected from the river or filled as part of revetment and levee reconstruction, would enlarge the scarce amount of connected off-channel habitat. These scour areas would provide important nesting, rearing, and resting habitat for avian species that frequent the Missouri River floodplain, including blue and snow geese, Canada geese, mallard, redwing black birds, killdeer and great blue heron (J. Smith, Missouri Department of Conservation, personal commun., 1994). Scour holes, although not natural floodplain habitats, are also expected to provide critical off-channel habitat for spawning, rearing, and over-wintering fishes (G. Farabee and J. Robinson, Missouri Department of Conservation, personal commun., 1994).

FRAMEWORK FOR RESTORATION

The SAST hosted a workshop of Upper Mississippi River Basin ecologists to develop questions for evaluating ecological impacts of the 1993 flood. Over 75 questions were drafted and are being used to (1) provide recommendations for additional information needs and analyses,

(2) provide an ecological perspective on measures to reduce flood risks and damage, and (3) contribute to developing environmentally and socially acceptable management alternatives for restoration of the upper Mississippi River-floodplain ecosystem.

The recommendations follow from concepts identified in the National Research Council's (NRC) 1992 report, "Restoration of Aquatic Ecosystems". The report defines the ideal natural state of a river-floodplain as being in "dynamic equilibrium". This is the idea that local features of a river are created, undergo change through time, and eventually disappear, while the overall pattern (e.g., meandering, braiding) remains constant on a larger spatial and temporal scale. Physical processes of rivers provide the template upon which biological processes are patterned. Figure 6.8 demonstrates this principle by illustrating the dependency of biological processes on periodic water level fluctuations in large floodplain rivers. The NRC report concludes, "The essence of a fluvial system is the dynamic equilibrium of the physical system, which in turn establishes a dynamic equilibrium in the biological components" (page 206). The dynamic equilibrium of the upper Mississippi, lower Missouri, and Illinois Rivers is best approximated by turn of the century conditions, since no unaltered reaches exist today. These conditions provide targets for river restoration programs. Periodic flooding was, and remains, vital to establishing and maintaining this dynamic equilibrium.

Three objectives should be addressed to begin restoration of these rivers to some semblance of a naturally functioning river-floodplain landscape within the context of competing human needs. First, attributes of ecological integrity for the river-floodplain landscape should be defined within the larger context of the entire Upper Mississippi River Basin. Keddy and others (1993) outline a process for choosing such indicators, using wetlands as a model ecosystem. Second, historic hydrologic, geomorphic, and ecologic information should be assembled and evaluated to define acceptable and desirable levels for the indicators. Third, relevant endpoints as indicators of ecosystem recovery should be identified (Kelly and Harwell, 1990). Evaluation of impacts from the flood of 1993 should include NRC's goal and supporting objectives for river restoration. The goal of restoration is defined as, "...to restore the river or stream to dynamic equilibrium, not to 'stabilize' a channel or bank".

Once the attributes of ecological integrity are defined and the historic and current data are acquired these should be analyzed to determine how well they meet the desired endpoints. The difference between the existing system and the desired end points indicates how nearly the existing system meets the goal of a healthy functioning acquatic ecosystem.

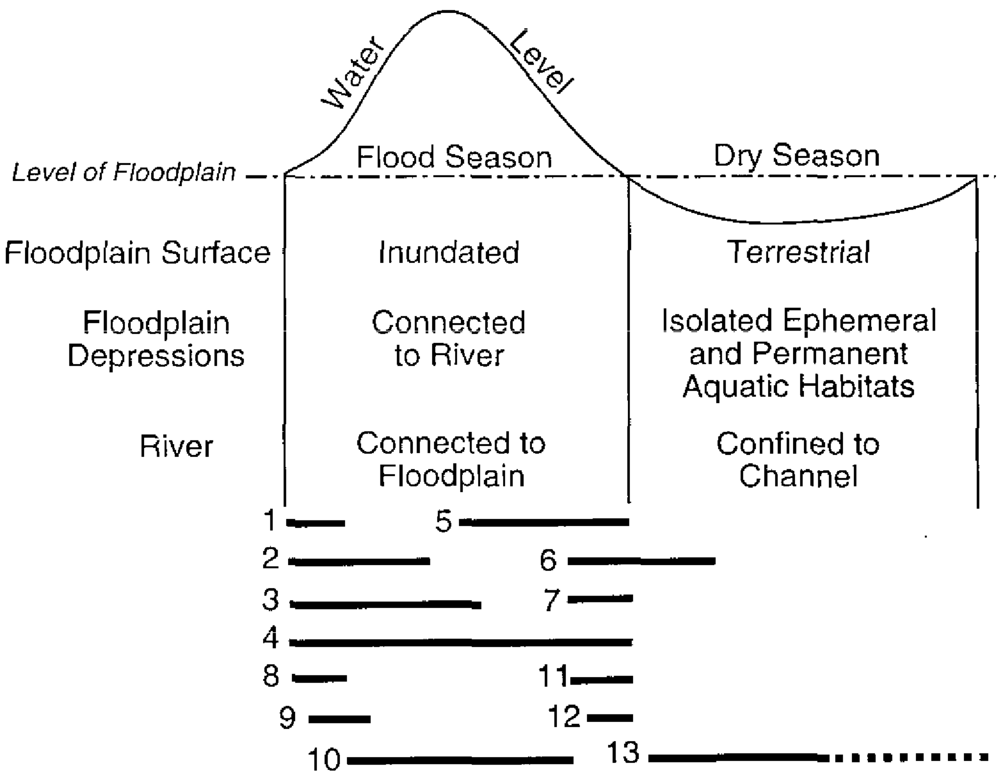


Figure 6.8 Idealized changes in water level over an annual cycle for a large floodplain river. Numbered horizontal bars indicate characteristic annual periodicity patterns for some major interactions as follows: (1) nutrients released as floodplain surface is flooded; (2) nutrient subsidy from connected river; (3) rapid growth of aquatic plants and invertebrates on floodplain; (4) major period of dead plant matter decomposition on floodplain; (5) Organic matter exported to the river; (6) maximum plankton production in floodplain depressions; (7) drift of plankton, bottom organisms and aquatic plants to river; (8) fishes enter floodplain from river; (9) major period of fish spawning on floodplain; (10) period of maximum fish growth; (11) fishes move from floodplain to river; (12) heavy fish predation losses to other vertebrates at mouth of drainage channels; (12) high mortality of fishes stranded in floodplain depressions provides forage to birds and mammals. (Ward 1989)

The NRC suggests four objectives to achieve this goal. Monitoring the ecosystem can provide information on whether or not the NRC objectives are being met.

1. Restore the natural sediment and water regime, where regime refers to the daily-to-seasonal variation in water and sediment loads and the annual-to-decadal patterns of floods and droughts.
2. Restore the natural channel geometry, if restoration of the water and sediment regime alone does not.
3. Restore the natural floodplain plant community, which becomes a functioning part of the channel geometry and floodplain hydrology.
4. Restore native aquatic and wetland plants and animals if they do not recolonize on their own.

These objectives, in conjunction with the social and economic values of water and hydropower, water-control structures, structures that are threatened by floods, erosion and sedimentation, and human needs for agriculture and recreation, form a sound basis on which to incorporate ecological restoration as part of integrated floodplain management. This approach considers not only structural methods of management, but also nonstructural methods, such as regulatory floodways, purchase of easements to prevent construction, and purchase of land and removal or relocation of structures (NRC, 1992). When stream or river management actions are taken without determining whether the aquatic ecosystem is in dynamic equilibrium or disequilibrium, the manager is gambling with the stream or river rather than ensuring improved ecosystem function and dynamic stability (Heede and Rinne, 1990).

RECOMMENDATIONS FOR ADDITIONAL INFORMATION AND ANALYSES

Rational and cost-effective decision making requires objective, science-based information. Hydraulic engineers, geomorphologists, ecologists, and other scientists should collectively identify those areas of the floodplain that have experienced recurrent flood damage, that pose the greatest risk for future flood damage, and that would provide significant environmental benefits if the river-floodplain connection were restored. Such locations are prime areas for implementing levee setbacks and floodplain wetland enhancement.

Issue identification and information acquisition have occupied most of the SAST effort to date; analysis thus far has been minimal. Consequently, these recommendations address the need for further study and analyses of various aspects of the basin's ecology. The goal is to develop an ecosystem-based analysis and model for management of the basin. These preliminary recommendations are grouped into two main categories: (1) inventorying and monitoring species, communities, and habitats to develop baselines from which to assess change, and (2) developing floodplain and basin-wide ecological models to assess impacts of changes in ecosystem variables based on change inputs to the system.

Inventorying and monitoring species, communities, and habitats

Inventory and monitoring activities must include river-floodplain physical processes, basin-wide ecology, river and floodplain ecology, and contaminants. Inventorying and monitoring define past and present states and provide resource managers with milestones to evaluate progress of restoration programs.

Recommendation 6.6: Develop an inventory of species, communities, and habitats and understanding of their functional interrelationships.

- **6.6a Analyze information on channel geometry and channel cross-sections for available historical river surveys on the Missouri and Mississippi Rivers.**
- **6.6b Document changes in land cover and land use and changes in the composition, distribution, and abundance of native and introduced flora and fauna over the last 100 years in the uplands and floodplains.**
- **6.6c Quantify distribution and area of floodplain wetlands at various flood stages under various levee scenarios.**
- **6.6d Identify sources, sinks, and transport mechanisms of nutrients, organic matter, and human pollutants in the river-floodplains and their major tributaries.**
- **6.6e Quantify the agricultural potential of lands in the floodplains with respect to other environmental benefits.**
- **6.6f Determine the characteristics of an appropriate flow regime (flood pulse and low flow) for maintaining a semblance of pre-control aquatic ecosystems.**

Developing floodplain and basin-wide ecological models

Conceptual models using information acquired under inventorying and monitoring must be developed to enhance our understanding of the interrelationships between ecosystem processes and human activities in the basin. Conceptual and mathematical ecological models must be integrated with rainfall-runoff and geomorphic models if the basin is to be fully modeled. Animations and visualization of the various processes would greatly enhance our ability to convey these complex issues. Building integrated models using animations or advanced visualization techniques would likely lead to further understanding of the interrelationships of the various hydrologic, hydraulic, geologic, ecologic and socio-economic processes and facilitate holistic river basin management.

Recommendation 6.7: Develop a basin-wide ecological model.

- **6.7a Define effects of sediment in runoff to streams and upland impoundments in relation to land management and stream riparian corridors.**
- **6.7b Determine effects of stream sinuosity on stream flows and flood stages.**
- **6.7c Evaluate floodplain wetlands with respect to flood stream hydraulics.**
- **6.7d Evaluate effects of riparian vegetation and other land covers on conveyance and storage of flood waters and the role of riparian corridors as energy dissipaters during flooding.**
- **6.7e Evaluate effects of upland restoration on stream hydraulics at both flood and low flows.**
- **6.7f Determine if, and how much, upland and floodplain wetlands influence flood peaks.**
- **6.7g Define environmental and ecological requirements of important aquatic and terrestrial river-floodplain species.**
- **6.7h Characterize the important compositional, structural, and functional interrelationships among plant and animal communities of the major Upper Mississippi River Basin rivers and their floodplains.**

Empirical Studies

While conceptual and mathematical models provide a useful method for understanding interrelationships of ecological processes and forecasting the effects of changes to the system, empirical analyses and assessment of actual changes are also necessary. This assessment requires implementation of proposed habitat restoration practices in areas of the various terrain types under consideration. The habitat restoration sites must be of sufficient size to refine the concepts described in this preliminary report. Selection of the sites should be based on potential value for ecological restoration and for geomorphologic and hydrodynamic considerations.

Recommendation 6.7: Establish ecological restoration sites on mainstem and tributary floodplains in the uplands.

- **6.7a Identify suitable locations for the sites.**
- **6.7b Develop criteria to measure the effectiveness of ecological restoration sites.**
- **6.7c Establish a monitoring system to determine how well the restoration sites are meeting the criteria.**
- **6.7d Modify the restoration and ecological management practices as new understanding is gained.**

The complex interactions of the physical and biological environment can form a dynamic equilibrium that enhances the flora and fauna in the river basin and, in particular, on the floodplains. The opportunity for this dynamic equilibrium to occur, however, is dependent on river-basin and floodplain management techniques that incorporate the needs of both the natural ecosystem and human activity. A basic understanding of both is necessary.

Section IV

THE ENGINEERED SYSTEM

The engineered system consists of changes society has made to the natural system by either physical or social means. People have engineered portions of the Upper Mississippi River Basin system since the Native American population conducted agricultural activities on the floodplains and burned off portions of the upland prairies while hunting buffalo. The engineered system has become more complex as society has developed and population has expanded. Engineering has affected the system in ways that were intended, and in some ways that were not intended. Both uplands and floodplains have been engineered for a variety of reasons, but the largest impact in the area has been the result of supporting agriculture. This is because the upper Midwest is one of the most highly productive agricultural areas in the world.

Section IV examines some aspects of upland practices for control of sedimentation and runoff, the mainstem floodplain levees, and the impact of the 1993 floods on crop production. Some models were run to examine the hydraulic effects of various types of land management practices on runoff from storms in the uplands and to examine the effects of levees on a selected portion of the mainstem rivers under various flood flow scenarios. Agricultural productivity in the region during the flood of 1993 is examined, and some issues in evaluating economic benefits of actions in the basin are discussed.

Chapter 7

UPLAND MANAGEMENT

NONSTRUCTURAL FLOOD REDUCTION

Nonstructural methods of flood reduction have long been encouraged in the United States. Often the methods have been associated with other goals such as capturing the maximum amount of rainfall for agricultural crops, or restoring prairie pothole wetlands for the use of waterfowl, or preventing erosion. These methods, while practiced to accomplish other goals, can provide flood reduction benefits. For example, the SCS for many years has encouraged treatment of farmland to reduce runoff and erosion, both of which affect flooding in a basin.

The water purification function of wetlands is now better understood and is being investigated and encouraged as a method of treating agricultural wastewater prior to returning it to streams. Some communities and organizations are also moving to restore and create wetlands as a part of a basin-wide policy to improve water quality. One such activity is the Redwood River Basin Association's effort to restore up to 5,000 acres of wetlands for water quality improvement (Cooper, 1994). These wetlands should not only improve water quality, but can also have an impact on flooding if properly restored, as will be discussed in a following section of this chapter.

With proper education and techniques, methods currently promoted for other purposes can be used or adapted to assist in flood reduction. For example, an awareness of the relationship of wetland types and their effect on flooding can result in actions in which wetlands restored for wildlife can assist in local flood reduction as well. Thus, wetland restoration not only can improve water quality from agricultural watersheds, but also can provide habitat for wildlife and, to some extent, reduce downstream flooding as well.

The construction of wetlands on the floodplains or in the watershed, however, can only reduce peak flooding to the maximum amount of their storage capacity. In large storms, the water volume stored in wetlands that form a small portion of the watershed can be negligible, but in watersheds with large amounts of wetlands in the upland, wetlands may have an appreciable effect on flooding. The effect of wetlands depends on the volume of wetland storage relative to the volume of the flood, the location of the wetland, and the duration of the flood.

Recent large floods are increasing public awareness that levees and flood control works do not guarantee that lands in the historic floodplain will never flood --- even if the lands are protected by levees and flood control works. Renewed awareness of the dangers of dwelling on the floodplain and weariness of fighting the rivers have prompted some residents to move to higher ground. Two examples are Soldiers Grove, Wisconsin, where the residents had moved the town prior to the 1993 event (Becker,1983), and Valmeyer, Illinois, which is in the process of being moved to high ground.

The National Flood Insurance Program has, to some extent, heightened awareness of the 100-year floodplain, and significant progress has been made in the past 20 years in floodplain management (Interagency Floodplain Management Task Force, 1992). Nonstructural measures such as floodproofing are being taken in some communities and in various floodplains, but the application is not widespread (IFMTF, 1992).

In contrast to programs that have been designed to keep water on the watershed, other programs have existed to drain lands with excess water to allow production of agricultural crops. This drainage of agricultural lands is prevalent in many areas of the basin - especially in areas where natural wetlands existed.

UPLAND AGRICULTURAL DRAINAGE

Over 60 percent of the depressions in the closed drainage areas of Iowa, Minnesota, and Illinois are tile or open ditch drained (USDA-SCS NRI data, 1982). Agricultural drainage systems are installed to lower the water table or remove surface water to (1) provide trafficable field operations, (2) protect crops from excess water conditions, and (3) control salinity in irrigated arid and semi-arid areas (Skaggs and others, 1994). Skaggs and others (1994) describe two stages of land modification for agricultural use and resulting changes in surface runoff and peak flows.

During the first stage, the land is cleared or plowed. This process decreases infiltration, increases the wetness of the land by lowering evapotranspiration, and increases surface runoff. Open ditch drains are then constructed to act as outlets for the removal of excess water. Since they are direct conduits to streams, these open ditches eliminate a high percentage of the surface storage of the depressional areas and can result in increased peak flows. Research results have shown that drainage improvement (surface drainage) plus land conversion from natural vegetation to row crops increases peak runoff rates at the field edge by a factor of 200 to 400 percent over the rates in the natural condition (Skaggs and others, 1994). Improved drainage also reduces time to runoff peaks.

During the second stage, tile drainage systems are developed for each field of a farm. The outlets for these systems are in the open ditches constructed in the first stage. Once installed, subsurface tile systems lower the water table and remove water from depressional areas at a commonly used design rate of 1.25 cm/day (1/2 inch/day). Traditional subsurface drainage systems lower the peak flows created in the first stage of drainage activity by 35 to 55 percent (Skaggs and others, 1994). By increasing storage capacity in the soils and storage in drained depressions, traditional tile results in controlled removal of water from depressions over a period of days and decreases the peak flows in streams. However, the combined effect of agricultural drainage increases flow in streams over surface flow from natural systems. Exact figures depend on topography, field drainage systems, and distance to open ditch systems.

Some tile drainage systems have standpipes from the soil surface to the tile line; they are used to lower the risk of crop failure from ponding of water in depressional areas. These standpipe tile drains are more efficient in removing water than traditional tile since the standpipe provides an open conduit from the surface ponded water to the tile line. Many tile drains to depressions have standpipes in the Des Moines Lobe area of Iowa and Minnesota (G. Schellentrager, personal commun., 1994). Maidment (Proceedings of SAST Hydrologic Modeling Workshop, forthcoming) found that, in the Walnut Creek watershed in Iowa, standpipe drains act more like open drainage systems, transmitting water directly to stream channels at rates that are near those of surface drainage. However, SCS sources (R. Bartels and D. Miller, written commun., 1994) note that the underground tile joined to the standpipe has limited capacity and that these drains have a throttling effect on flow from depressional areas. Further study is needed to determine the impact of standpipe tile drains on stream flow.

Traditional tile drainage systems help keep the depressions empty and thus provide the maximum amount of surface water storage, so that full storage capacity is realized during rainfall events. The tile systems then drain the depressions in a controlled manner over a period of a few days. This drainage has the effect of broadening the peak of the hydrograph and decreasing flow rates in comparison with open ditch systems. Tile systems with standpipes, however, drain water to streams at rates that may approach those of surface drains, depending on the size of the tile and the magnitude of the storm, and therefore may not be effective for surface storage of water.

FEDERAL PROGRAMS INVOLVED

Existing land use in the basin is guided by Federal, state, and local programs, regulations, and law. The programs that have the largest potential for impacting flooding are the Food Security Act of 1985 (FSA) and the Food, Agriculture, Conservation, and Trade Act of 1990 (FACTA). These acts impose restrictions on persons who participate in certain USDA programs and who plant agricultural commodities on highly erodible lands or converted wetlands. The erosion provisions of the FSA and FACTA farm bills relate directly to surface water runoff. Practices such as residue management and reduced tillage increase infiltration of water into the soil and reduce the amount of surface water runoff. The reduction of surface water runoff will

Figure 7.1 The Food Security Act of 1985 (FSA) and the Food, Agriculture, Conservation, and Trade Act of 1990 (FACTA) impose restrictions on the persons who participate in certain USDA programs and who plant agricultural commodities on highly erodible lands or converted wetlands. The erosion provisions of the FSA and FACTA farm bills relate directly to surface water runoff. Practices such as residue management and reduced tillage increase infiltration of water into the soils and reduce the amount of surface water runoff. The reduction of surface water runoff will directly affect peak flows of streams, including flood events. Wetlands, especially potholes, provide surface storage of water and thus reduce peak flows during flood events.

This map shows the total reduction in runoff due to the land management activities in compliance with FSA and FACTA, and includes the reduction due to the Conservation Reserve Program (CRP) as shown on a companion map.

The Soil Conservation Service uses hydrologic runoff curve numbers (CN's) to indicate surface runoff potential from various soil cover complexes. Change in land treatment affects curve number. Increase in soil surface cover resulting from FSA-FACTA reduces CN's. Reduced CN was the measure used to estimate effect on flood runoff. Reductions in runoff for four flooding frequencies were calculated over the nine-state region. For example, a curve number reduction in the range of 3.0 - 3.9 would result in a reduction runoff of 12 to 15 percent for a five year flood (0.20 annual probability). Peak flood flow is closely proportional to the flood runoff volume. Thus, peak flow would be reduced approximately the same percentage as runoff volume.

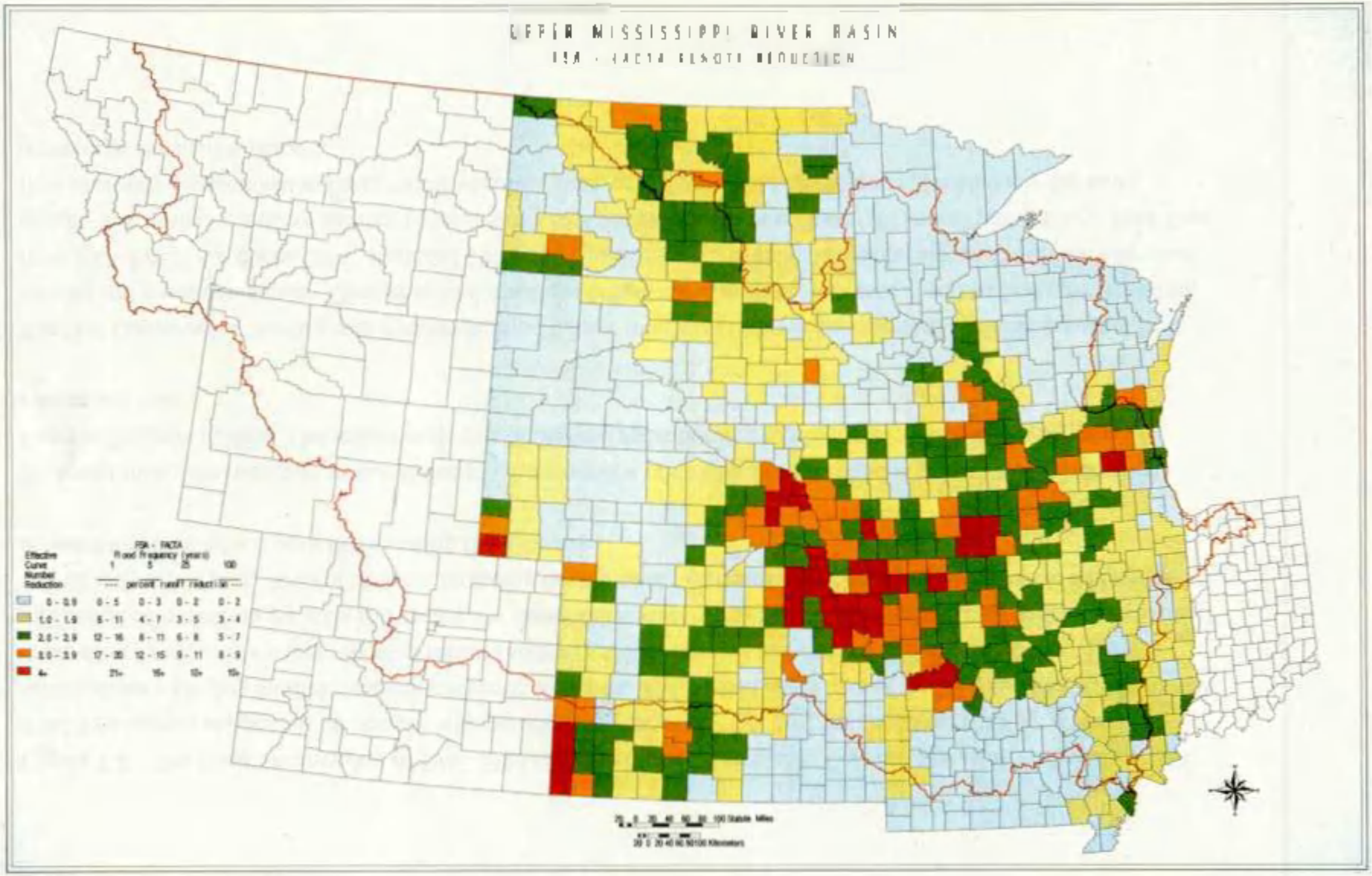
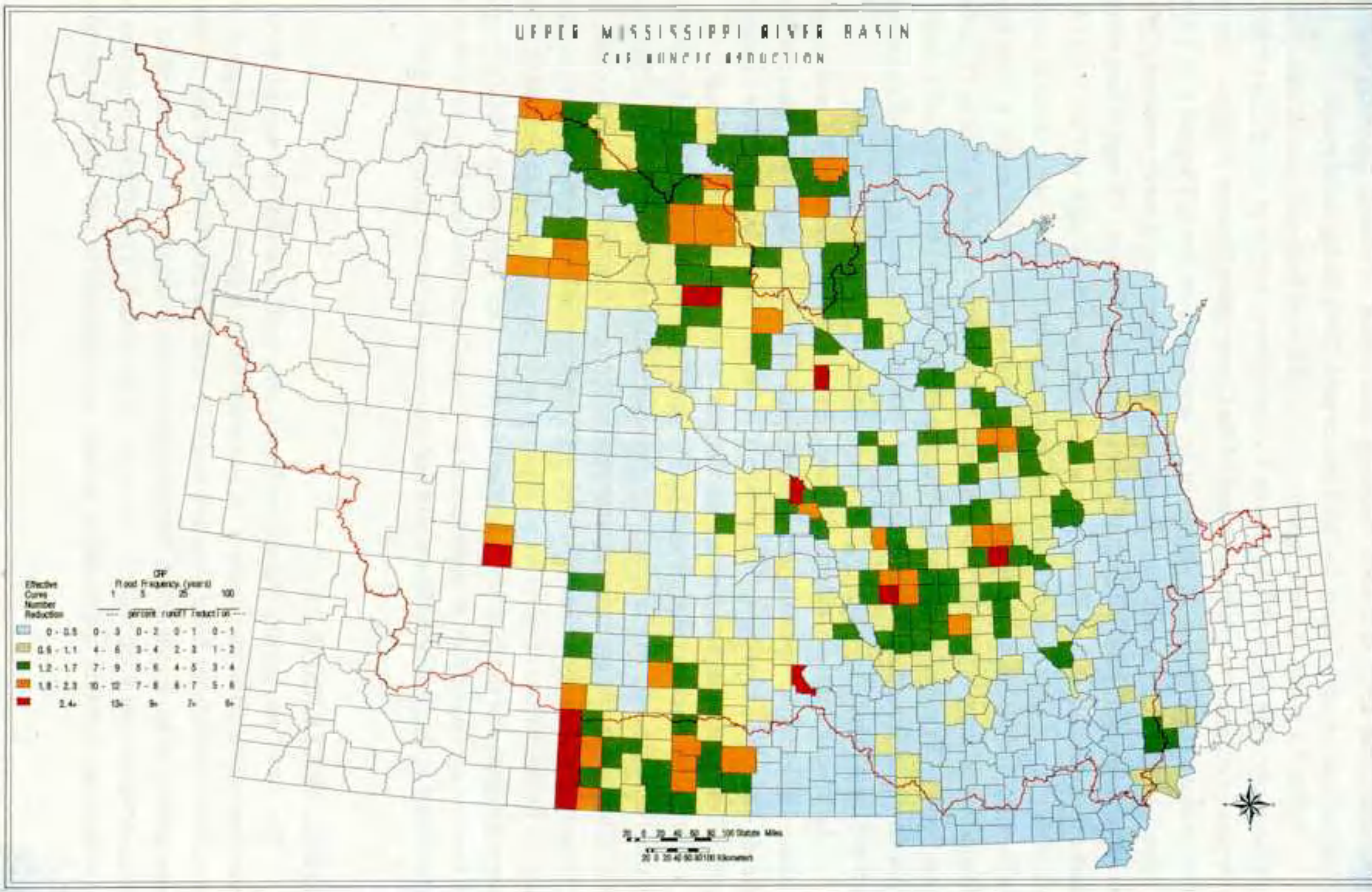

UPPER MISSISSIPPI RIVER BASIN
FSA - FACTA RUNOFF REDUCTION
Effective Curve Number Reduction
FSA - FACTA
Flood Frequency (years)
1 5 25 100
percent runoff reduction
0 - 0.9 0 - 5 0 - 3 0 - 2 0 - 2
1.0 - 1.9 6 - 11 4 - 7 3 - 5 3 - 4
2.0 - 2.9 12 - 16 8 - 11 6 - 8 5 - 7
3.0 - 3.9 17 - 20 12 - 15 9 - 11 8 - 9
4+ 21+ 16+ 12+ 10+
Statute Miles
Kilometers

Figure 7.2 The Food Security Act of 1985 (FSA) and the Flood, Agriculture, Conservation, and Trade Act of 1990 (FACTA) impose restrictions on persons who participate in certain USDA programs and who plant agricultural commodities on highly erodible lands or converted wetlands. The erosion provisions of the FSA and FACTA farm bills relate directly to surface water runoff. Practices such as residue management and reduced tillage increase runoff infiltration of water into the soils and reduce the amount of surface water runoff. The reduction of surface water runoff will directly affect peak flows of streams, including flood events. Wetlands, especially potholes, provide surface storage of water and thus reduce peak flows during flood events.

This map shows the reduction in runoff due to the conversion of cropland to grassland as part of the Conservation Reserve Program (CRP). This reduction is part of the total reduction due to FSA and FACTA as shown on a companion map.

The Soil Conservation Service uses hydrologic runoff curve numbers (CN's) to indicate surface runoff potential from various soil cover complexes. Change in land treatment affects curve number. Increase in soil surface cover resulting from FSA-FACTA reduces CN's. Reduced CN was the measure used to estimate effect calculated over the nine-state region. For example, a curve number reduction of 7 to 8 percent for a 5-year flood (.20 annual probability). Peak flood flow is closely proportional to flood runoff volume. Thus, peak flow would be reduced approximately the same percentage as runoff volume.


UPPER MISSISSIPPI RIVER BASIN
CRP RUNOFF REDUCTION
Effective Curve Number Reduction
CRP Flood Frequency (years)
1 5 25 100
percent runoff reduction
0 - 0.5 0 - 3 0 - 2 0 - 1 0 - 1
0.6 - 1.1 4 - 6 3 - 4 2 - 3 1 - 2
1.2 - 1.7 7 - 9 5 - 6 4 - 5 3 - 4
1.8 - 2.3 10 - 12 7 - 8 6 - 7 5 - 6
2.4+ 13+ 9+ 7+ 6+
Statute Miles
Kilometers

directly affect peak flows of streams, including flood events. Wetlands, especially potholes, provide surface storage of water and thus reduce peak flows during flood events.

Figure 7.1 shows the total reduction in runoff due to land management activities in compliance with FSA and FACTA. Figure 7.2 shows the reduction in runoff due to the conversion of cropland to grassland as part of the Conservation Reserve Program. The runoff reduction due to CRP (figure 7.2) is part of the total reduction due to FSA and FACTA as shown in figure 7.1. The Soil Conservation Service uses hydrologic runoff curve numbers (CN's) to indicate surface runoff potential from various soil-cover complexes. Change in land treatment affects curve number: that is, increases in soil surface cover resulting from FSA-FACTA reduce CN's; and, reduced CN's indicate higher infiltration and lower runoff. Reductions in runoff for four flooding frequencies were calculated over the 9-state area. For example, a curve number reduction in the range of 3.0 to 3.9 would result in a reduction in runoff of 12 to 15 percent for a 5-year flood (0.20 annual probability). Peak flood flow is related to flood runoff volume, but further modeling is needed to determine actual peak reductions due to timing of runoff within the basin and basin shape.

Additionally, the wetland conservation provisions of FSA and FACTA encourage the protection of wetlands, especially in the pothole region of the drainage basin. These pothole wetlands (figure 7.2) provide surface storage of water and thus reduce peak flows during flood events. These programs, however, are not designed to restore converted wetlands.

Programs, such as these entailed by FSA and FACTA, that encourage infiltration of water into the soil and thereby reduce runoff are important to fully attain the potential subsoil storage of water. These programs are especially important in the open drainage areas of the basin, since subsoil storage is one of the few (if not the only) nonstructural approaches to reducing stream flows. In formerly closed (depressional) drainage areas, programs such as the USDA Wetland Reserve Program and the DOI Small Wetland Acquisition and Partners for Wildlife Programs, which encourage reclamation of depressional or wetland areas that have been open ditch drained, are important to decreasing surface runoff and improving the water quality of the area.

MODEL WATERSHEDS

The SAST was initially charged with evaluating both structural and nonstructural approaches to river basin management. It was immediately apparent that the best place to apply nonstructural methods for flood reduction would be in the uplands because of the comparatively greater amount of lands available in the upland than in the floodplain areas. In an effort to evaluate nonstructural flood reduction measures in the uplands, a preliminary evaluation of upland land treatments, wetlands, and detention storage was conducted to view the range of reductions in flood peaks that might be possible on various types of watersheds. In order to apply the results as widely as possible, watersheds were selected to represent basins that differed in terrain as widely as possible.

Since time was the critical constraint, the selection of watersheds was driven by the existence of calibrated models for watersheds that were to be evaluated. An initial search indicated that a calibrated SCS TR-20 model was in use for the Whitebreast Creek for design of detention structures, a USACE HEC-1 model existed for the Boone River watershed, and a HEC-1 model for the West Fork Cedar River could be developed with the use of GEOSHED software developed by the Brigham Young University Computer Graphics Laboratory. Later, a TR-20 model that existed for the Redwood River basin was also discovered. The four selected watersheds represent distinct types of landscapes - a steep basin, a low relief pothole basin, a low relief basin with well defined drainage, and a relatively high relief basin that has been drained for agriculture. It should be noted that while the Whitebreast Creek and Redwood River studies were rather detailed (especially the Whitebreast Creek model), the Boone River and West Fork Cedar River models used much less detail due to time constraints and the lack of pre-existing detailed models.

The SAST recognized that since different models were used for the study basins, the results might not compare exactly. The general trends, however, would be identifiable for each watershed and the relative differences could be noted between the watersheds. Time constraints and the need to answer important questions regarding wetlands and flood reductions, SCS land practices, and detention basin effects, dictated the use of two different hydrologic models. Additionally, four groups of modelers were used in the studies to facilitate timely completion of the modeling. The basins and associated modeling groups are: Boone River - Corps of Engineers, Hydrologic Engineering Center (HEC, 1994); West Fork Cedar River - Corps of Engineers, Waterways Experiment Station (WES, 1994); Whitebreast Creek - USDA-SCS, Iowa (SCS, 1994a); and Redwood River - USDA-SCS, Minnesota (SCS, 1994b).

The SCS curve number method was used for all studies where land management practices were evaluated. It was easier to model upland wetlands and detention basins with the TR-20 model than with the HEC-1 model. A recently developed interface and visualization package for HEC-1 known as GEOSHED was utilized for the West Fork Cedar River. The GEOSHED software facilitated the set-up and visualization of results for the HEC-1 model. It would have been impossible to set up and calibrate a new model for the West Fork Cedar River without the GEOSHED HEC-1 interface in the time available for the SAST studies.

Storm durations of 24 hours were used, with the exception of the Boone River and Redwood River basins where a 24-hour storm would not account for the long travel time of about 90 hours to reach the basin outlets. The storm duration used for the Boone River was a 4-day

(96 hour) storm and for the Redwood River basin the duration was a 6-day (144 hour) storm. This difference in duration means that flood volumes between the two watershed sets (pothole versus non-pothole) are not directly comparable.

All model runs used antecedent moisture condition II for the start of modeling conditions. Condition II is defined as the average soil moisture condition prior to the annual flood event. For the 1993 flood, antecedent condition III existed in most areas. Condition III indicates near saturated soils prior to the storm and gives significantly higher runoff than antecedent moisture conditions I (dry enough to cultivate) or II. Time constraints precluded modeling antecedent conditions I and III. Additionally, standard modeling practice uses antecedent condition II as a starting condition for the modeling of standard storm events.

The watersheds used for land practice and land use studies were originally selected to represent three distinct areas of the Upper Mississippi River Basin as determined by the USDA Major Land Resource Areas (MLRA). The fourth watershed (Redwood River), used for a more detailed evaluation of wetlands, was selected on the basis of available data concerning wetland drainage and the pre-existence of a calibrated hydrologic model. The upper end of the Redwood River basin also represents a fourth Major Land Resource Area. After completion of the model studies and during production of the map overlays using data in the SAST database, it was discovered that the West Fork Cedar basin is actually located within 3 MLRA's, rather than on the boundary of two of the areas and within the third MLRA as originally determined.

The basin locations and associated MLRA boundaries are shown in figure 7.3 and are described as

Boone River above the gage near Webster City, Iowa, MLRA 103 - Central Iowa and Minnesota Till Prairie, a relatively flat watershed with low relief prairie pothole terrain, 840 sq. miles;

West Fork Cedar River above the gage near Finchford, Iowa, MLRA 104, 108, and 103 - Eastern Iowa and Minnesota Till Prairie, Central Iowa and Minnesota Till Prairie, and Illinois and Iowa Deep Loess and Drift Plain, a relatively flat watershed but having a well defined drainage system, 850 sq. miles;

Whitebreast Creek above the gage near Dallas, Iowa, MLRA 108 and 109 - Illinois and Iowa Deep Loess and Drift, and Iowa and Missouri Heavy Till Plain, a relatively steep watershed with well incised drainage, 380 sq. miles;

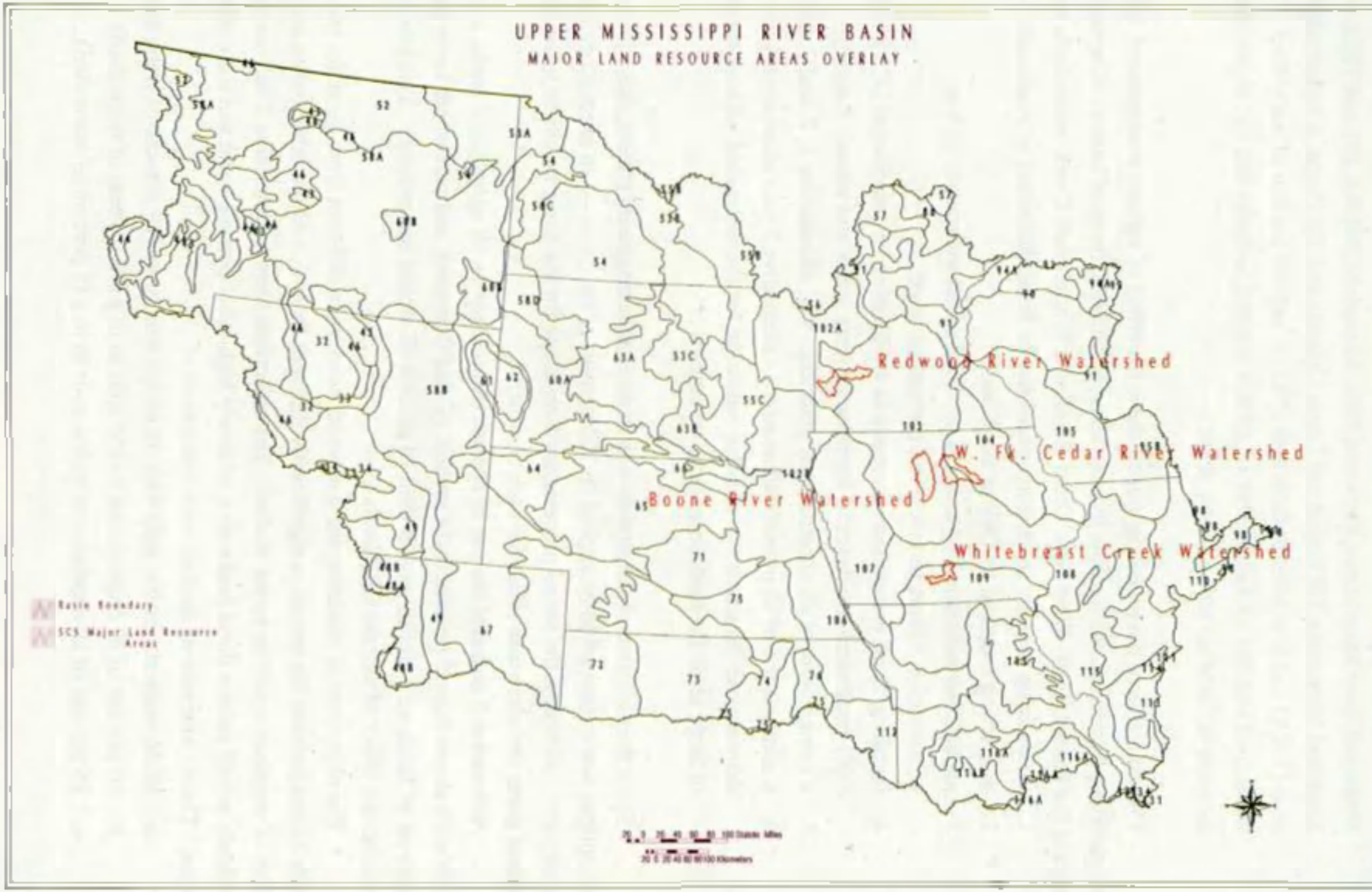

UPPER MISSISSIPPI RIVER BASIN
MAJOR LAND RESOURCE AREAS OVERLAY
Redwood River Watershed
W. Fk. Cedar River Watershed
Boone River Watershed
Whitebreast Creek Watershed
Basin Boundary
SCS Major Land Resource Areas

Figure 7.3

Redwood River basin above Redwood Falls, Minnesota, MLRA 103 and 102A - Central Iowa and Minnesota Till Prairie and Loess Uplands and Till Plains, a higher relief pothole area (102A) and low relief pothole area (103) in eastern portion of watershed. This watershed also has a large number of surface drained potholes and has experienced an increase in flood severity, 700 sq. miles.

The objective of the modeling was to show the effect of various management, land use, and storage practices on the outflow hydrographs for differing types of basins. Alternatives selected for Boone River, West Fork Cedar River, and Whitebreast Creek watersheds were

1. maximizing wetland storage in upland and/or floodplain areas as applicable,
2. converting cropland to CRP as available,
3. maximizing infiltration by using all applicable land treatments such as conservation tillage, terraces, and permanent cover,
4. installing flood prevention structures as applicable - i.e., traditional SCS small (P.L. 566) watershed structures to temporarily store water and release it slowly,
5. a combination of all nonstructural practices - i.e., alternatives 1, 2, and 3, and
6. a combination of all possible alternatives - alternative 5 plus alternative 4 to demonstrate the maximum possible reduction for the watershed without the inundation of large areas for medium to large reservoirs.

Since the objective of the studies was to determine maximum effects, these treatments and options were assumed to be applied to 100 percent of the basin --- an unrealistically high assumption. Although the actual percentage of coverage for the basin would be lower, this method gives the maximum effect for each alternative.

Alternative 3 included the use of conservation tillage on all agricultural lands, terraces on lands with slopes from 5 percent to 14 percent (C and D slopes), and permanent cover (grass, trees) on all lands with slopes greater than 14 percent (E slopes and greater). This alternative also included the effect of current CRP lands.

The objectives of modeling the Redwood River were different from those for the other study basins because the terrain is significantly different from that of the other basins and the effect of wetlands could be better studied. The objectives were to determine if increasing wetlands would reduce flood peaks on a relatively high-relief pothole basin and if so, to what extent. The six alternatives studied were restoration of

a. all depressional hydric soils with detention structures (19 percent of watershed),
b. 50 percent of all depressional hydric soils as in a (10 percent of watershed),
c. 25 percent of all depressional hydric soils as in a (5 percent of watershed),

d. small wetlands with 50 percent assumed to be landlocked - i.e., 50 percent had no outlet to stream after restoration while the remaining 50 percent served as detention structures,
e. large wetlands and lakes over 100 acres in size, and
f. large and small wetlands (combine alternatives a and e) with no assumption of landlocked wetlands.

Since the purpose of the Redwood River study was to determine the effect of wetlands, no SCS land treatments (CRP or maximum infiltration) were applied to the Redwood River basin. Additionally, with the exception of alternative d, the wetlands were assumed to be restored as detention storage areas. This assumption means that the water stored in the wetland would be released slowly through a control structure over a period of several days, making the full storage of the wetland available for a subsequent storm. Using full storage maximized the effect of the wetlands on flooding in the watershed simulation.

The hydrologic models were calibrated for conditions existing at the time of the selected storms. Since not all of the watersheds experienced flooding in the 1993 event, the models were calibrated to the largest event for which sufficient rainfall and flow records existed. The Whitebreast Creek model, for example, was calibrated to a storm from the fall of 1992 which was larger than any event for that watershed in 1993, while the West Fork Cedar River was calibrated to a July 1990 event. For the Whitebreast Creek, since CRP lands were in place in 1992, the model first calibrated flows with CRP lands in the model. The CRP lands were then removed from the model which was rerun to give a base condition. Thus, the base conditions are for no land treatment or detention basins in place. Results are given in percent reduction in peak discharge from base conditions with no practices in place (i.e., after adjustment to remove the effects of current CRP lands). The four events evaluated for all watersheds were the 1-, 5-, 25-, and 100-year storms[1].

Not all land treatments are readily adaptable to all watersheds. The construction of detention basins, for example, is most economically feasible in watersheds with incised drainageways. A tour of the West Fork Cedar River basin revealed very few possible sites for detention basins, and since the available sites were deemed too few to provide a significant impact, this option was not modeled for the basin. Similarly, too few wetland areas were found in

[1] The recurrence interval of the storm does not necessarily correspond to the flood recurrence interval due to such variables as atmospheric conditions, season, antecedent soil moisture conditions, temporary or permanent changes in land use and land cover, or temporary or permanent changes in floodplain morphology.

the West Fork Cedar River basin to have an impact. It should be noted that an off-stream wildlife site exists in this basin, but a shallow depth (approximately 4-5 ft) would cover several thousand acres. This makes the construction of detention basins or wetlands in the basin a very land-intensive undertaking. Detention structures were not evaluated on the Boone River since few, if any, sites exist in the watershed, while some potential for wetland development or restoration would exist.

Results of Watershed Studies

The results of the four watershed studies are presented in table 7.1. The results of the Redwood River study also correspond to three cases that were tested for the other three watersheds. The maximum result for Redwood River tests is also shown in table 7.1 for comparison. It should be noted that the Redwood River options did not include any of the SCS land treatments on the uplands which could increase flood peak reductions from the basin. The results of the combination of all applicable alternatives for the Boone River, West Fork Cedar River, and Whitebreast Creek are plotted in figure 7.4, as are the results for the maximum alternative d for the Redwood River. Alternative d (small wetland restoration with 50 percent landlocked) produced the greatest overall reduction in flood peaks for the Redwood River. Any amount of additional peak reduction for the Redwood River basin resulting from land treatment would have to be determined by an additional modeling effort.

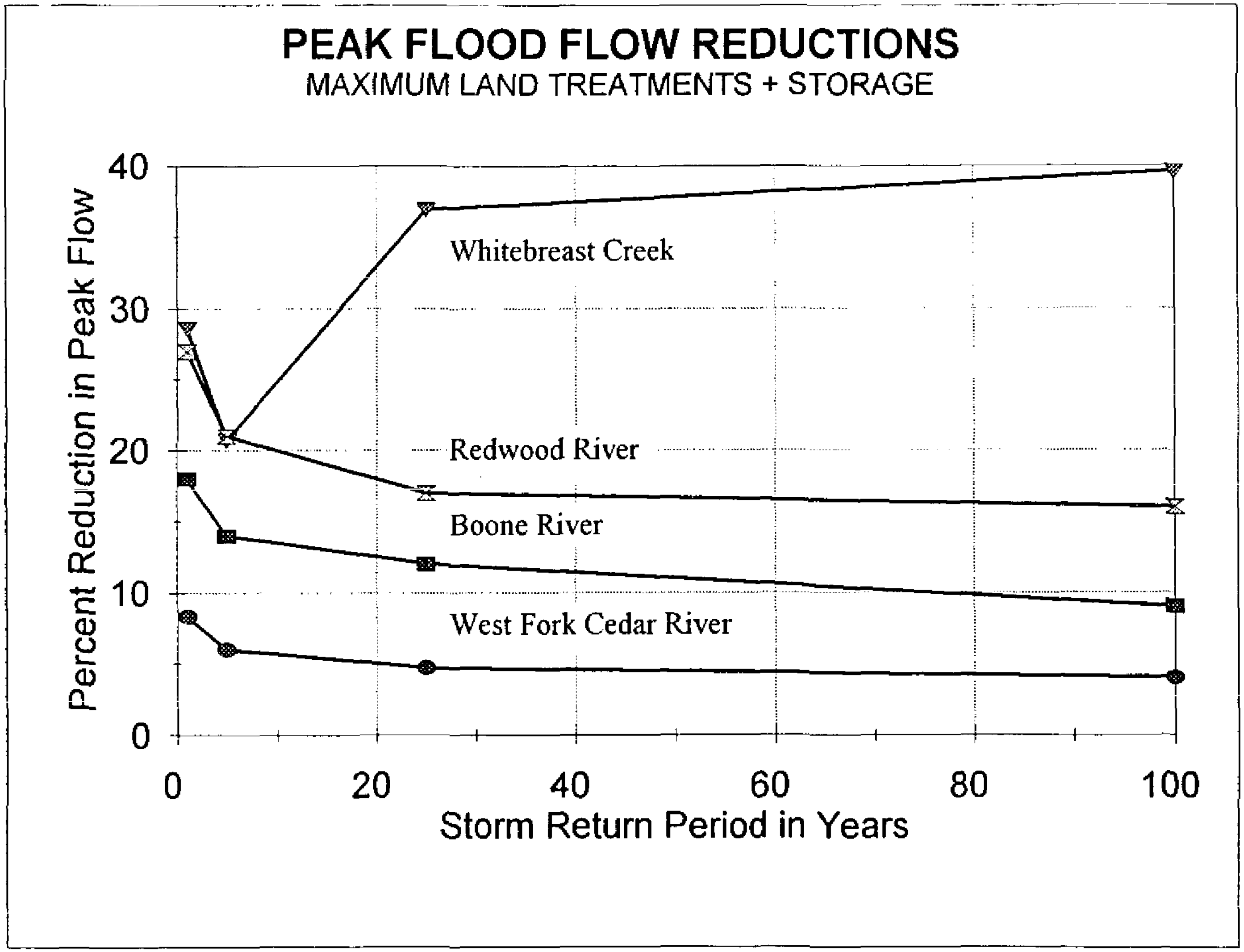
Three of the watersheds (figure 7.4) show a trend of reducing effect with increasing storm return period for the combination of all modeled alternatives, while the Whitebreast Creek model shows the opposite effect for 5-year or greater storms. It should be noted that when the design capacity of detention basins is exceeded, the effectiveness of the basins for flood peak reduction decreases to zero as the amount of overflow increases. Analysis of table 7.1 shows that the maximum infiltration option (FSA) at Whitebreast Creek results in a rather variable reduction that is nearly as high for the 100-year storm as it is for the 1-year storm. This result and the results for the detention basins are probably due to the timing of runoff in the watershed and the interaction of the detention storage and storage in terraces. The results have been closely scrutinized by the Iowa SCS State Office staff and are believed to be accurate. This variation is an excellent example of the reason why results from one basin cannot be directly applied to other basins.

Table 7.1

PERCENT (%) FLOOD PEAK REDUCTION BY WATERSHED AND TREATMENT				
RETURN PERIOD	Boone River	W. Fk. Cedar	Whitebreast Creek	Redwood River
FLOODPLAIN WETLANDS				
				(Option e)
1	5		0.5	6
5	3		0.8	5
25	2		2	3
100	2		-0.2	3
UPLAND WETLANDS OR POTHOLES				
				(Option a)
1	9			23
5	8			15
25	7			11
100	5			10
CONSERVATION RESERVE PROGRAM LANDS (CRP)				
1	3	7.1	4.4	
5	1	4.8	4	
25	1	3.7	4	
100	1	3.1	4	
MAXIMUM INFILTRATION (FSA)				
1	6	8.3	20.6	
5	3	6	14.8	
25	2	4.7	17.9	
100	2	4	20.4	
DETENTION STRUCTURES				
				(Option f)
1			7.7	26
5			14.8	16
25			26.8	12
100			28.1	11
TOTAL OF ALL APPLICABLE TREATMENTS*				
				(Option d)
1	18	8.3	28.6	27
5	14	6	20.7	21
25	12	4.7	36.9	17
100	9	4	39.6	16

* For Redwood River selected option is maximum of those tested.
Assumes 100% coverage by all applicable treatments

Figure 7.4


PEAK FLOOD FLOW REDUCTIONS
MAXIMUM LAND TREATMENTS + STORAGE
Percent Reduction in Peak Flow
Storm Return Period in Years
Whitebreast Creek
Redwood River
Boone River
West Fork Cedar River
0
10
20
30
40
0
20
40
60
80
100

Floodplain Wetlands

The effect of upland wetlands in the floodplain of higher order streams was modeled for three basins. The results (table 7.1) show that in areas where significant wetlands exist, they can have a noticeable effect on discharge peaks from the basin. The difference can be seen between the Whitebreast Creek results and the results for the Boone and Redwood River basins. Whitebreast Creek is a steeper basin, while the other basins that have larger floodplains showed larger reductions in flood peaks. Although the peak reductions are not large, 5 to 6 percent maximum for the 1-year flood and 2 to 3 percent for the 100-year storms, they are noticeable for smaller storms. On the steeper Whitebreast Creek basin, floodplain wetlands had no significant effect except possibly for the 50-year storm, but again the results do not follow the trends from the other watersheds.

Upland Wetlands

The effects of wetlands in the uplands were modeled only for the basins with potholes since the other basins did not have significantly large or numerous areas that would be amenable to wetland development or restoration. The two basins where upland wetlands were modeled produce differing results as shown in table 7.1, with the Boone showing a 9 percent reduction in peak discharge for the 1-year event and a 5 percent reduction for the 100-year event, while the Redwood basin shows a 23 percent reduction of the 1-year event and a 10 percent reduction for the 100-year event.

Part of the difference in reduction is the topography of the two basins. The Boone basin is very flat with very low relief potholes, while the Redwood basin has significantly more relief and thus more storage volume available for flood water detention. Additionally, the characterization of potholes for the Boone River basin was taken from 7.5 minute USGS topographic maps and is fairly imprecise. Many of the potholes in this region may be only a few feet deep and do not show up on current USGS 7.5 minute quadrangles. To more accurately model low relief watersheds such as the Boone River, much better quality elevation data are needed; however, the information is very costly. An alternative is to use TM data and aerial photographs to determine areal extent of potholes, then conduct field studies and a statistical sample to determine storage capacity. If a more accurate model is created for the Boone River, it is anticipated that the modeled flood peak reductions resulting from upland wetlands could be higher but not as high as the reductions noted on the Redwood River because of storage differences between the watersheds. No significant amount of upland wetlands was found in the West Fork Cedar River or in the Whitebreast Creek watersheds, so this alternative was not modeled for these watersheds.

Recommendation 7.1: Acquire higher resolution topographic data for areas of the basin where low relief potholes exist to allow more accurate determination of pothole storage volumes.

Conservation Reserve Program Lands (CRP)

The tests to determine CRP land effectiveness in reducing flood peaks produced mixed results. The results for Whitebreast Creek indicate the same amount of reduction (4 percent) regardless of storm size up to the 100-year storm. No explanation can be given for the consistency of these results at this time. For the other watersheds, the effects of CRP on flood peaks indicate that for the West Fork Cedar River the reductions are significantly higher than for the Boone River - 7 percent versus 3 percent for the 1-year storm, and 3 percent versus 1 percent for the 100-year storm on the Boone River. Part of this difference is the amount of lands that qualify for inclusion in the CRP program. The Boone River watershed is relatively flat and has a limited amount of land classified as highly erodible land - a necessary classification for inclusion in the CRP program. Additionally, the terrain surrounding the West Fork Cedar River is steeper than the pothole terrain that makes up the Boone River basin.

Maximum Infiltration Option (FSA)

The maximum infiltration alternative was effective on all three watersheds to which it was applied, but was especially effective on the steep Whitebreast Creek watershed. Reductions vary from 20 percent for Whitebreast Creek to 2 percent and 4 percent for the Boone and West Fork Cedar basins respectively for the 100-year storm. The results from Whitebreast Creek again do not follow the trend of the other basins. This difference is due to the amount of steep land in the watershed and the effect of terraces and other practices in increasing infiltration and reducing runoff. If the simulation had been done using a wetter antecedent moisture condition, similar to the condition that existed in 1993 prior to the heavy rains, the peak reductions would have been less, since as much water would not have infiltrated into the soils. This decreased infiltration would result in much smaller reductions in peak flows. For dry conditions (antecedent moisture condition I), the maximum infiltration alternative would probably result in high reductions in peak flows. The results show a general trend for the greatest reduction in the basin with the steepest lands, intermediate reductions in the basin with intermediate slopes, and lowest reductions in the flattest basin. These results show the importance of land treatment in reducing runoff on steeply sloping lands.

Detention Structures

The two basins where detention structures were modeled were Whitebreast Creek and Redwood River. The alternative for the Redwood River watershed is actually identical to the alternative 1 for Whitebreast Creek and the alternatives are directly comparable. The results from Whitebreast Creek are not what were expected and may be the result of basin timing, shape, or location of the detention structures in the watershed. If storm sizes were increased, the result expected is that the structures would eventually lose control of the flow, and reductions due to the detention structures would become zero. It is possible that the shape of the Whitebreast Creek watershed plays a role in the differing results, since it is more elongated than the other three basins and the timing of the flows from the various sub-basins has a significant effect on the results. The results from the Redwood River follow the trend that was expected. The effect of land treatments and wetlands decreased with increasing storm sizes. Flood peak reductions ranged from 26 percent for the 1-year storm to 11 percent for the 100-year storm, while the reductions for Whitebreast Creek increased from 8 percent for the 1-year storm to 28 percent for the 100-year storm. The results of this study must be further analyzed.

Empirical Studies

Field tests help refine understanding of the impact of different land management practices on water and sediment dynamics and on the agriculture and ecology of the areas where tests are conducted. Indications are that various physiographic regions respond differently to land management practices and have different values for agriculture and habitat restoration. Models alone cannot completely evaluate the effects of alternative land use and the responses of components of the system to land use and land management changes over time. To obtain qualitative and quantitative information about system impacts and responses, and to make systems models more reliable, field studies and demonstration projects must be conducted.

Recommendation 7.2: Conduct field trials and demonstration projects to determine the effect of various land management practices on flood dynamics, sedimentation and soil conservation, agriculture, and habitat restoration. These studies should be conducted in a variety of physiographic regions.

CONCLUSIONS

Modeling studies demonstrate that land use, land management, and detention alternatives can be applied with varying degrees of success in reducing peak flood flows, depending on basin topography. Currently recommended SCS conservation practices can be effective in reducing peak runoff from basins, depending on slope, topography, and storm size. Generally as the storm magnitude increases, upland treatment measures are less effective in decreasing peak flows, although land treatment was effective even for the 100-year storm on the Whitebreast Creek watershed. Further study is needed to determine how these results apply to other areas of the basin.

Recommendation 7.3: Model additional watersheds within the basin to better estimate the flood reduction effects of upland treatment measures for other terrain types.

Detention structures or wetlands can aid in lowering flood peaks where opportunity exists, but wetlands cannot be used in all watersheds to effectively reduce flood peaks. This is primarily due to watershed morphology and amount of wetlands or potential wetlands available. In the watersheds modeled, the maximum reduction for floodplain wetlands was 6 percent of the peak flood discharge for a 1-year event and 3 percent for a 100-year storm. Wetlands were most effective in upland areas with more deeply incised potholes, such as the Redwood River watershed, where reductions were 23 percent of the 1-year event and 10 percent of the 100-year event. In areas of shallow depressions, such as the Boone River basin, restored wetlands reduced peak discharge by 9 percent for the 1-year event and 5 percent for the 100-year event. However, longer duration storms were necessary to model these two watersheds because of the long travel time to reach the basin outlets. Therefore, the effect of upland pothole wetlands on flood peaks reduction is most likely understated for at least the higher frequency storms. Further research is needed on upland watersheds.

In general, upland treatments are more effective in reducing flood peaks for smaller and more frequent storms than for larger, less frequent storms. However, more studies on different landscapes are needed to fully understand the effect of land treatment and wetland restoration on flood peaks.

For modeling-low relief areas such as the Boone River watershed, current topographic products are less than adequate and need to be upgraded to give better representations of basin topography.

Chapter 8

LEVEES

STRUCTURAL FLOOD CONTROL

Human beings have lived in the Upper Mississippi River Basin for several thousand years. The floodplain played an important role in these early cultures, some of which had substantial populations, earthworks, and material production (Bareis and Porter, 1984; Emerson and Lewis, 1991; Smith, 1990). Human impacts in the basin within the last 200 years have included clearing of the floodplains and upland areas for agricultural production, removal of snags from the channels for navigation, narrowing and dredging of the channel for navigation, construction of navigation dams, protection of cities and floodplains by the construction of levees, and the construction of large multipurpose reservoirs to provide power, water for irrigation, municipal/rural/industrial water supplies, recreation, flood control, and other public benefits.

During the early to mid-1800's, communities began to grow on the floodplains of the upper Mississippi and Missouri Rivers to take advantage of the transportation network that was developing on the rivers and the proximity to water for the population. Because rivers were the early major transportation links, some of the towns and cities were located on the floodplain near the river channel or on high areas at the river's edge and expanded into flood prone areas. Later, as farming spread inland from the rivers and the road networks began to improve, towns were located on the uplands.. Some of today's major cities were already growing rapidly and, for cities and towns that relied on the rivers for the greater part of their transportation and commerce, location at the river's edge was critical.

The fact that the cities were located at the river's edge meant that either the cities must tolerate flooding, or some type of protection must be constructed to protect the cities from flooding. After much debate regarding levees and other methods of flood protection, the policy that led to the construction of levees for local protection was developed (Humphrey and Abbot, 1861). When these failed due to excessive river flows, flood control reservoirs were constructed upstream to store flood waters and release them slowly.

Besides commerce, the other major floodplain activity was agriculture. The floodplain of the rivers often contained the most fertile land in the country and was of prime value for agricultural production. A logical result of farming in the floodplains was that owners who had struggled to clear these highly productive lands wanted to protect them from flood waters. This desire to protect their investment from floods led to demands for agricultural levees along the river as well as flood control storage upstream to reduce the required levee heights. Protection of the floodplain investments that were encouraged by a century of national policy has resulted in nearly continuous levee systems along the upper Mississippi and the lower Missouri Rivers.

In an effort to protect adjacent farmlands and provide ample space for flood passage, the Pick-Sloan plan was adopted by Congress as a part of the Flood Control Act of 1944. This plan called for a floodway from Sioux City to the mouth of the Missouri that was 3,000 feet wide from Sioux City to Kansas City and 5,000 feet wide below Kansas City, in addition to more than 100 reservoirs throughout the Missouri River basin. This legislation included authority for the 5 multipurpose mainstem dams on the Missouri River (Ferrell, 1993).

In 1962, based on new construction methods for levees, additional reservoirs, and flood control structures, it was recommended that the floodway be decreased to 3,000 feet in width for the entire length. This recommendation was based on proposed reservoirs on the Grand River that were never constructed. Federal levees that were constructed in an effort to protect highly productive agricultural lands along the river were built in accordance with the calculated floodway requirements. The private levee systems that were built along the Missouri River were placed as close to the river as possible, and for the most part do not allow for the recommended floodway. A study done by the USACE Waterways Experiment Station for FEMA showed that agricultural levees had little effect (less than about 1 foot) on flood stage for 100-year floods on the Missouri River from Waverly to Jefferson City, Missouri, because the relatively low levee heights would overtop during major flood events (Hall, 1991) --- precisely what happened during the 1993 flood event.

Today the upper Mississippi River below Muscatine, Iowa, and the lower Missouri River below Sioux City, Iowa, are flanked by agricultural and municipal levees for most of their length. Reservoirs control most of the flows on the Missouri River, while flood flows on the Mississippi are only slightly affected by reservoir regulation. The levees, flow regulation, and human encroachment have contributed to the loss of wetlands and environmental changes along the rivers. These environmental problems must be balanced with flood control if the diverse species in these reaches of the rivers are to preserved or enhanced.

It should be noted that these river systems are dynamic and extremely variable. Little is known about the historic channels of the Missouri and Mississippi Rivers before the early 1800's when policy began to be directed toward controlling the rivers for navigation or flood control purposes.

The earliest known survey that has been evaluated for river widths seems to be about 1821 when river widths were slightly wider than those that exist currently on the middle Mississippi River (Simons and others, 1974). A survey from 1809 has also been located by the Environmental Management Technical Center (EMTC) in Onalaska, Wisconsin, but has not yet been evaluated for river widths. Simons' analysis dated the end of the natural river system at 1888, but much of the floodplain clearing had been done before that time, and dikes had already been built in St. Louis to constrict the river from 4,200 feet wide to 2,100 feet --- the same width of the river today at St. Louis. The 1821 width at St. Louis was 3,100 feet. In the 1840's the river at St. Louis had expanded from 3,100 feet to 4,200 feet and had become so shallow that navigation was threatened. This may have been due to major floods at about this time or to a combination of the floods and the clearing of floodplain lands that was underway by the 1840's.

Floods have been common on the upper Mississippi and Missouri Rivers. As a result of flooding, multipurpose reservoirs (including flood control) have been constructed on most major tributaries and on the main stem of the Missouri River. For the 1993 flood, while damages were in the $10-16 billion range, additional damages estimated at about $15-19 billion were prevented by the U.S. Army Corps of Engineers flood control structures and reservoirs in the system (USACE, unpublished data, 1994).

FLOOD EROSION AND SEDIMENTATION EFFECTS OF LEVEES

Many existing flood control systems in the Upper Mississippi River Basin currently protect life and property on the floodplain and have prevented considerable damage in urban and industrial areas. During the 1993 flood on the lower Missouri River, however, levee breaches in agricultural areas focused flood-flow energy at hundreds of sites resulting in extraordinary levee damage, deep scour, and extensive sand deposition on the floodplain (figure 8.1). Locally, constricted flood flow in breaches through railway embankments and in the vicinity of railroad and highway bridges also acted to focus flood-flow energy, thereby adding to the scour and sand deposition problems. On average, approximately 7 percent of the floodplain between the Grand River and St. Charles was seriously and significantly impacted by these processes.

LEVEE-INDUCED FLOOD SCOUR AND SEDIMENTATION EFFECTS

Analysis of aerial photographs, Landsat TM images, and historical maps of the lower Missouri River floodplain reveals that more than 90 percent of the erosional and depositional features of the 1993 flood are associated with breached flood-control levees (Dohrenwend and others, 1994). Typically, levee breaches are located on or near channel banks (1) along the down valley bank at the upstream end of tight meander loops, (2) at points of intersection between the present channel and older channels, (3) along tributaries crossing the high-energy floodplain, and (4) at various locations downstream of large levee breaches where coherent, high-velocity flow was established across the floodplain. Levee <u>scour holes</u>, locally known as "blow holes" or "blew holes", are extraordinarily deep holes eroded into floodplain alluvial deposits by high intensity flood scour related to constricted flow through levee breaches. Levee scour holes typically are centered in and attain their greatest depths along the line of the levee breach. Small levee scour holes are generally circular, 100 to 250 feet in diameter. Large scour holes are elongate and as much as 900 to 1,500 feet wide and 3,000 feet long. Maximum depths of levee scour holes are 25 to 55 feet (preliminary data, USACE; Missouri Department of Conservation; Chrazastowski and others, 1994). Erosionally scoured and stripped zones that cut through the soil plow zone and into underlying substrata commonly formed immediately downstream of the deep scour holes. Within these scour zones, shallow parallel channels and grooves, as much as five feet deep, and scattered scour holes, as much as 15 deep and 200 feet long formed along major flood flow paths. These erosional zones extend as far as one mile downstream from the largest levee breaches (Dohrenwend and others, 1994). In Illinois, similar erosional scars extend as much as 1300 feet downstream from several breaches along the Mississippi River (Chrazastowski and others, 1994). Along the lower Missouri River between Kansas City and St. Louis, where more than 500 scour holes formed in levee breaches, cobbles in deposits derived from these holes indicate that the depth of scour in many instances penetrated through the entire thickness of Holocene-age alluvial deposits into the underlying glacial outwash sediments (figure 8.1).

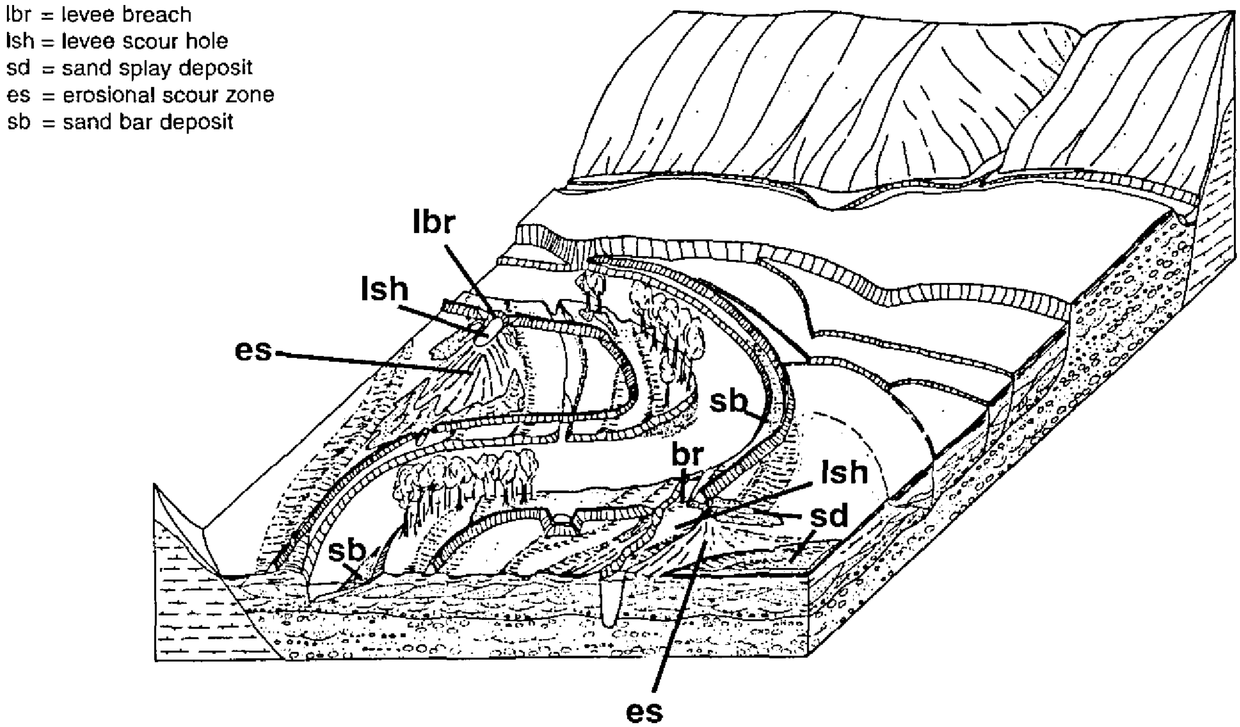


Figure 8.1. Missouri River, post large flood conditions.

Thick deposits resulting from the 1993 floods on the lower Missouri River are mostly limited to the high-energy floodplain zone. Moderately thick to thick sand deposits locally cover more than 50 percent of the floodplain in narrow bottomland areas, (for example, south of Glasgow: Lisbon Bottoms, Jameson Island). In contrast, moderate to thick flood deposits cover less than 3 to 5 percent of the floodplain along most other reaches, particularly those areas upstream from Glasgow where the floodplain attains widths of as much as 6 to 10 miles. Deposits related to levee breaches are extensive, fan- or crescent-shaped bodies of sand that are thick enough to conceal preexisting features of the floodplain surface. At the downstream margins of the scour zones associated with these levee breaches, crescentic sand sheets, as much as 3 to 10 feet thick, formed where the flood flow fanned out from the levee break. These crescent-shaped sand bodies locally extend as much as several hundred meters downstream from the scour zone margin. Other thick sand deposits were laid down where the flood current was dispersed in the lee of trees and buildings, in borrow pits adjacent to levees, and in the river channel. Thin fine-grained flood deposits were deposited discontinuously in areas distant from active channel belt; however, these thin deposits present no adverse long-term impact. Indeed, the thin clayey silt deposits are, for the most part, highly beneficial to long-term agricultural productivity.

MISSOURI RIVER LEVEES

The present system of agricultural flood-control levees along the lower Missouri River floodplain is an aggregate of levees constructed by different agencies and individuals at various times and under various programs (Missouri River Basin Commission, 1982). Their physical composition, elevation above the river channel, and locations vary from area to area. Some are on or near the channel bank and extend across old river-channel deposits. Others are setback to the landward margin of the high-energy floodplain to permit flood flow conveyance. In some areas, multiple levees have been built successively riverward during the past four decades. Many levees have a riverward fringe of riparian forest on the active floodplain. The levee system lacks coordinated planning and management. Design and coordination processes for existing private levee districts are needed to effectively manage levee protection. Many districts with levees designed for high-magnitude floods have been flooded between 5 and 10 times during the past 50 years (table 8.1), a history which reflects on the location and the design capacity of many of these levees. In addition, failures have often been catastrophic, resulting in substantial deep scour accompanied by concomitant deposition of thick sand deposits over significant areas of the floodplain. Within the reach from Glasgow to St. Louis (about 225 river miles), approximately 5 to 7 percent of the floodplain (13,000 to 18,000 acres) was substantially damaged as a result of the levee breaches during the 1993 flood (see Part I, figure 2.6). Based on preliminary analysis, 90 to 95 percent of this deep scour and thick sand deposition on the lower Missouri River was directly related to levee breaches.

Eyewitness accounts indicate that the majority of levee breaches were caused by overtopping, subsequent incision by gullies, and rapid flood-flow erosion (figure 8.2). However, levee failures may have also been caused by underflow and piping beneath the levee (manifested by sand boils along the landward base of the levee), and by interflow and piping within the levee structure itself (resulting in levee failure by either gullying or slumping of the levee face). Levee districts and individuals, responding to a SAST questionnaire, attributed levee damage to all of these erosional processes. However, accuracy of these assessments is unverified and the assessment of the cause of the levee breach may have been in part related to wording of the original questionnaire. Although the relative importance of these various levee-breaching processes is not well documented, eyewitness accounts suggest that each of these processes operated during the 1993 flood on the lower Missouri River.

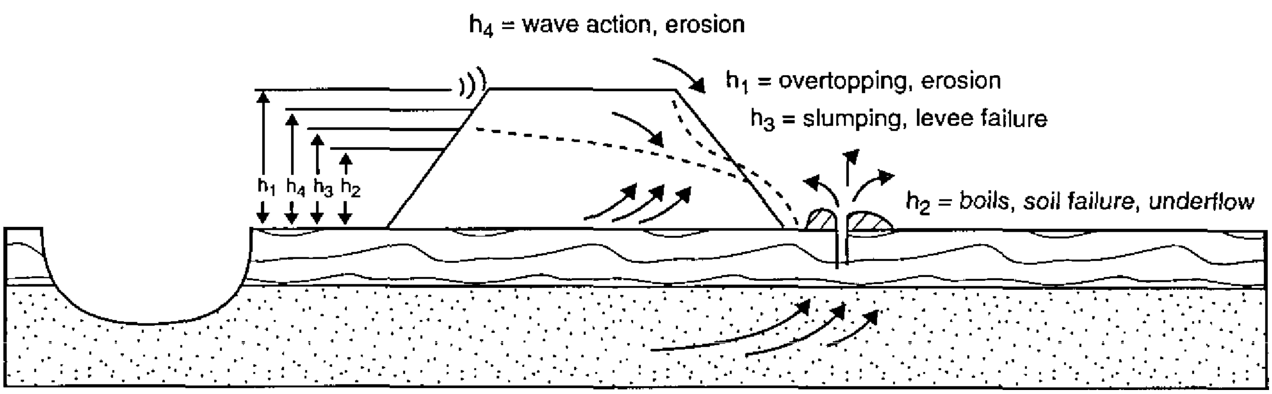


Figure 8.2. Conceptual levee failure mechanisms (modified from Bogardi and Mathe, 1968). The lowest water levels that trigger phenomena causing levee breaches are indicated by h_1, h_2, h_3, h_4 on the left side of the diagram. The phenomena that they cause are listed on the right side of the diagram.

Recommendation 8.1: The USACE in cooperation with USGS and SCS should conduct a detailed historical analysis of levee breaching to document specific levee locations and causes of high failure rates. This study should include geotechnical data and new field studies of hydraulic and geomorphologic factors that directly affect levee erosion and failure.

The majority of levee breaks resulting from the 1993 flood are associated with one or more of the following floodplain settings:

(1) areas occupied by one or more active channels within the past 120 years (72 percent)
(2) areas along downstream channel banks between the initiation and inflection points of meanders (17 percent)
(3) areas along tributary channels subjected to significant cross flow conditions during flooding (17 percent)
(4) areas along chutes (minor subsidiary channels) (8 percent)

The percentage of each setting indicates relative abundance within the 225-mile reach between Glasgow and St. Louis.

Factors contributing to levee breaks along the Missouri-Mississippi Rivers include

(1) highly permeable substrata composed of channel-sand deposits with or without a thin silt-clay cap;
(2) channel banks subject to high-energy flow conditions at
  (a) downstream banks of meanders between points of initiation and inflection, and
  (b) channel banks opposite deflecting cross flows on tributary, chute or flood channel;
(3) levee irregularities and (or) discontinuities at
  (a) high-angle junctions between levee segments and,
  (b) repaired levees that ring old levee scour holes;
(4) inadequate levee design, construction, repair; and
(5) inadequate levee maintenance.

Preliminary geomorphic mapping of the Missouri River floodplain and preliminary analysis of the spatial distribution of levee failures during the 1993 flood indicate that many reaches are particularly susceptible to catastrophic levee failure and(or) extensive deep scour and thick sand deposition. These reaches located by approximate river-mile (RM) that are shown on standard 7.5-minute topographic quadrangles (USGS), include

(1) areas of high amplitude-short wavelength meanders (loop bottoms)
  (a) Rhoades Island (RM 237; Marshall 1:100,000 map sheet)

(b) Lisbon Bottom to Wallace Island (RM 205 to RM 222; Moberly 1:100,000 map sheet)

(c) Easley to Hartsburg (RM 151 to RM 175; Jefferson City 1:100,000 map sheet)

(2) long-bottom areas where remnants of historic channels intersect the upstream end and extend along much of the length of the long bottom

(a) Miami-DeWitt Bottom (RM 252; Marshall 1:100,000 map sheet)

(b) Overton Bottom (RM 180; Jefferson City 1:100,000 map sheet)

(c) Berger Bottom, Boeuf Island (RM 82 to RM 92; Fulton 1:100,000 map sheet)

(d) Boeuf Island (RM 78 to RM 82, Fulton 1:100,000 map sheet)

(3) areas with significant floodplain constrictions (artificial structures, such as bridges, powerplants, etc.)

(a) I-70 bridge-Overton Bottoms (RM 180; Jefferson City 1:100,000 map sheet)

(b) powerplant-Labadie Bottoms (RM-54 to RM 57; St. Louis 1:100,000 map sheet)

Recommendation 8.2: On the basis of detailed floodplain mapping and historical levee evaluation, the USACE in cooperation with USGS and SCS should identify alternative alignments for levees with high failure rates.

One levee district near Wakenda, Missouri (Marshall 1:100,000-scale USGS map sheet) was passively flooded when a levee on the downstream side of the district failed during rising flood stage. Levee segments in the upstream portion of the levee district were not breached during maximum flood stage. Another example of such passive flooding and resultant mitigation of flood erosion is cited by Chrazastowski and others (1994).

Recommendation 8.3: On the basis of new hydraulic modeling of design floods, USACE and USGS should develop new levee designs that permit passive flooding of protected areas during major flood events to reduce levee damage and floodplain erosion and sedimentation associated with levee breaches under high head conditions.

Table 8.1
History of levee damage for the lower Missouri River for selected levee districts.

Levee Damage History - Lower Missouri River

A sample of levee districts that were severely impacted by the 1993 Flood

USACE #	District (Area) Name	Damage Years								
9F	Mittler et. al.	'45	'46	'52	'53	'58	'66	'73	'82	'86
16	Darst Bottoms	'44	'50	'58	'60	'61	'73	'86		
18 - Sec 4	Labadie Bottoms	'42	'47	'51	'58	'67	'73	'86		
23	Pinckney-Peers	'42	'44	'48	'51	'73	'86			
24	Berger Bottoms	'42	'44	'48	'51	'57	'61	'73	'86	
44	Overton Bottoms	'42	'47	'48	'51	'57	'65	'73	'82	'86
51	Lisbon Bottoms	'43	'44	'48	'52	'59	'60	'67	'69	'73
		'79	'82	'86						
53H	Cambridge	'82	'83	'84	'85					
55A - Sec 2	Rhoades Island	'61	'73	'74	'82	'83	'84	'86		
60A	Miami - DeWitt	'43	'47	'51	'67					

Levee Damage Summary

Lower Missouri River --- Grand River to St. Louis

1:100,000 Map Sheet	Floodplain Miles	Total Breaks	Historic River Channels	High Energy Reaches	Tributaries	Chutes
St. Louis	51	103	67%	15%	17%	13%
Fulton	61	121	74%	15%	23%	14%
Jefferson City	63	197	76%	16%	14%	3%
Moberly	26	83	66%	24%	13%	6%
Marshall	59	119	35%	16%	05%	37%
Total	260	623	72%	17%	17%	8%

LEVEE DATA BASE

It was clear from the beginning of SAST activities that a geographically referenced set of levee data is necessary for systemwide analysis and management on the floodplain. Such a data set did not exist and it was necessary for the SAST to create it. The SAST worked with the USACE to develop that data set.

The data set consists of locations of levees, elevations at specific points along the levees, levee sponsorship, dates of breaches or overtopping (1993 and previous) if known, area protected, levee length, eligibility for PL-84-99, and cost of 1993 repairs. Additional data are included in the database depending on availability.

This data set is valuable for river modeling efforts, emergency operations, floodplain management, and the visualization of flooding. The levee data set has required a major effort to collect, enter, and ensure the quality of the data. If these data are not maintained and updated as additional information becomes available or levee configuration changes, the value of the data set will be significantly reduced. A major part of the data set is the inclusion of as many privately owned levees and associated data as could be located. This is the part of the data set that will be most difficult to maintain but which will be of great value to future modeling and emergency operations efforts. Levees that are modified or left unrepaired must be included for accurate modeling of the Upper Mississippi River Basin. Since the data are of most value to the Corps of Engineers for modeling and operations, it would make sense that the data set should be maintained by USACE. Currently, the SCS is directly involved in levee repair through the emergency watershed program. SCS should be involved in improving the initial levee data set, and any further SCS repair work should be recorded in the data set by levee.

Recommendation 8.4: The levee data set should be maintained by the USACE in coordination and cooperation with the SCS and the states. Currency should be maintained on the levee data set. It should be part of the clearinghouse and access should be available to interested parties through the clearinghouse.

THE UNET MODEL

A one-dimensional unsteady flow hydraulic model was developed for a portion of the Mississippi River and its associated floodplains to test the effects of the current levee system on the flood of 1993 and other selected floods. The mathematical model used for the analysis was the UNET model currently supported by Dr. Robert Barkau (Barkau, 1993). The UNET model is an unsteady flow model that is suited for modeling long reaches of rivers where the dynamic effects of levee breaches, backwater conditions, bed slopes of less than one foot per mile, and varying flow rates along the river are important. All of these effects are important for understanding the processes of the 1993 flood and the effects of levees on floods. Actual modeling was done by Dr. Barkau under contract with SAST using optimization techniques he developed. Barkau (1994) points out that the unsteady flow equations are effective to define one-dimensional flow where the dynamics represent the looped rating curve effect. That is, the maximum flow does not coincide with maximum stage and there is rapid attenuation of the flood wave.

To run the UNET model, specific data are necessary. These data simulate river geometry and flow conditions:

1. river cross-sections,
2. Manning's "n" values (roughness coefficients),
3. observed flow and stage data for model calibration, and
4. boundary conditions of flow and stage.

All of these data were available or derived for the actual flood condition for which the model was calibrated.

The UNET model was developed for the reach of the Mississippi River from near Hannibal, Missouri (lock and dam 22 tailwater) to Cairo, Illinois; the Missouri River from Hermann, Missouri (river mile 97.9) to the mouth; the Illinois River from near Meredosia (river mile 70.8) to the mouth; and the Kaskaskia, Merimec, and Salt Rivers from the mouth upstream to the first river gaging station. The dendritic form of the Middle Mississippi River is the most simple form that can be modeled. The area covered by the model is shown schematically in figure 8.3. (Barkau, 1994). The model extends from L&D 22 TW at river mile 30.1 on the Mississippi River to Cairo at river mile 0.0. All major tributaries entering the Mississippi River are modeled from the last rated gage downstream to the mouth to reproduce the effects of backwater on the outflows.

The model included cross-sections that were originally developed by the Kansas City and St. Louis Districts of the Corps of Engineers. The cross-section data vary in age from about 10 to 20 years but were the only data that could be obtained in sufficient time for the SAST effort. The geometry of the river system is described by 1,218 cross-sections that extend from bluff to bluff. The cross-sections are entered at an interval of approximately .5 miles. The origin and age of the cross-sections are given in table 8.2 (Barkau, 1994). The model was calibrated and analysis was conducted for three events: the 1993, 1986, and 1973 floods.

Figure 8.3 Stream components in the Mississippi River model and the location of the principal gages.

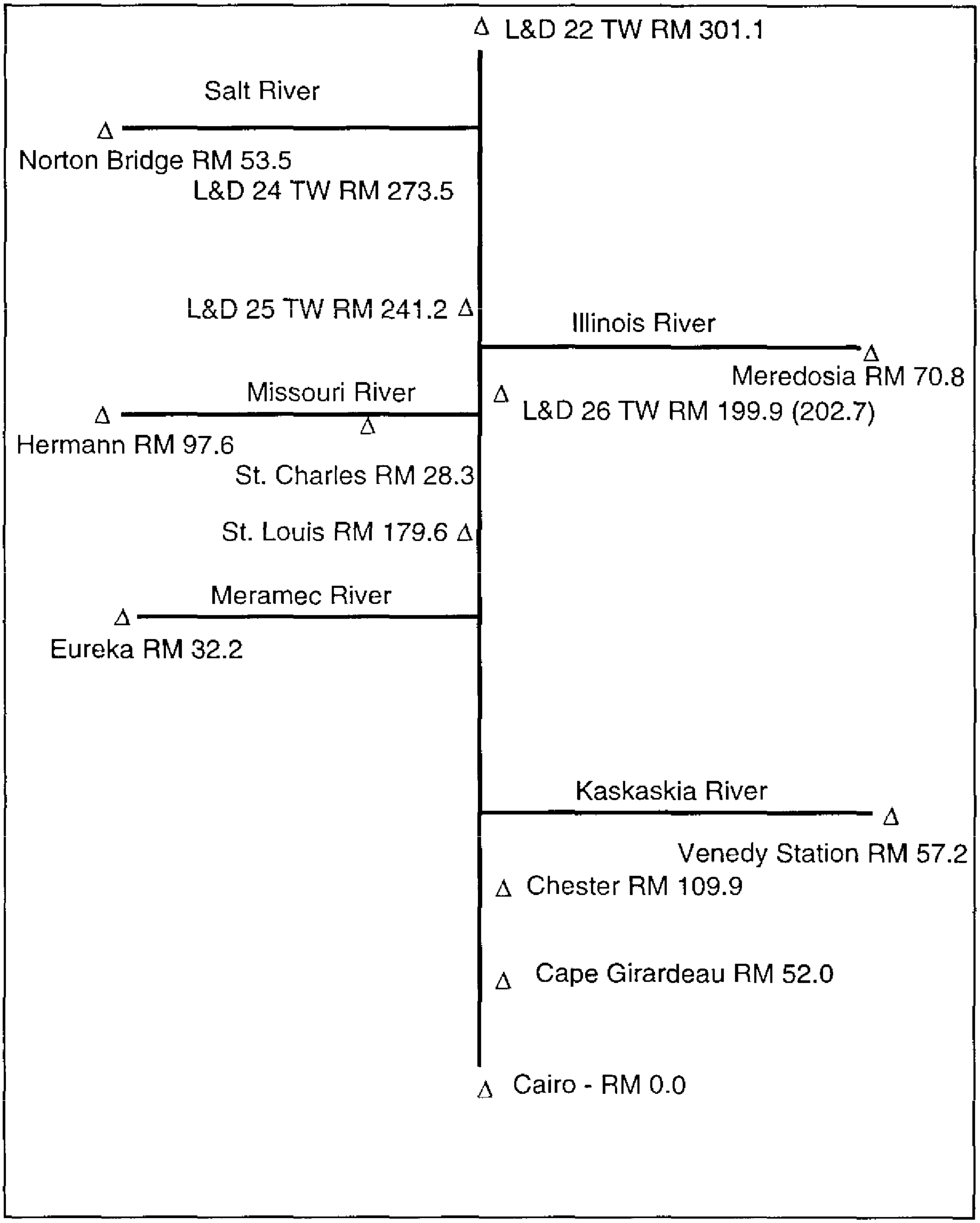


Table 8.2 Origin of the cross-sections in the Middle Mississippi River Model

Stream	Source	Overbank Cross-Section	Approximate Age in Years
Mississippi River	Gary Dyhouse, St. Louis District, Corps of Engineers	From 7.5 minute quadrangle maps	15
Illinois River	Gary Dyhouse, St. Louis District, Corps of Engineers	From 7.5 minute quadrangle maps	20
Missouri River	Claron Kuntz, Kansas City District, Corps of Engineers	Surveyed	18
Meramec River	Gary Dyhouse, St. Louis District, Corps of Engineers	Surveyed	20
Kaskaskia River	Gary Dyhouse, St. Louis District, Corps of Engineers	From 7.5 minute quadrangle maps	10
Salt River	Bob Barkau, St. Louis District, Corps of Engineers	From 7.5 minute quadrangle maps	20

(Barkau, 1994)

The 1993 Flood Event

The effects of levees were analyzed after calibrating the model to the flood of 1993 with the levees as they existed prior to the flood. Levees were overtopped or breached in the model at the same time as they were overtopped or breached during the flood, and the filling rate of areas protected by the levees was adjusted to match observed data where data were available. After the model was adjusted to accurately match the observed stage and flow data for river gaging stations, several levee configurations were tested. The options evaluated were

1. no-agricultural-levees,
2. no breaching or overtopping of any levees,
3. the Pick-Sloan Floodway for the Missouri River, and
4. a hypothetical floodway for the Missouri River supplied by the SAST.

The no-agricultural-levee configuration removed from the model all levees that were primarily protecting agricultural areas. This removal left in the model only levees in the St. Louis area whose primary role is to protect urban areas. The urban levees were left in place since it was considered that levees around major metropolitan and industrial areas would be maintained in current management practice in the foreseeable future. Scenario 2 modeled infinitely high and strong levees to see what the effect would have been if none of the levees in the system had failed. The configuration with the Pick-Sloan Floodway consisted of a 5,000 foot floodway for the entire reach of the Missouri River modeled as Scenario 3 in this study. The fourth scenario involved the placement of a SAST specified floodway that varied in width according to the geomorphology and historical channel widths of the area in which the cross-section was located.

During the 1993 event, the Missouri River reclaimed its floodplain and was actively conveying water through formerly leveed areas. In order to model this condition, the cross-section geometry needed extensive revision. The time required for this revision was not available to the SAST, and stage data reported for the various Missouri River levee configurations are for the second peak of the 1993 Missouri River flood, rather than for the third and highest peak. The effect of this recapture of the floodplain can be seen in data from the Hermann gage shown in table 8.3. From the July 8th peak to the July 30th peak, an increase in flow of 79 percent resulted in a stage increase of only 1 foot. Between the July 8th peak and the July 16th peak, the stage decreased by 0.2 feet, while flow increased by 21 percent. The modeling effort could handle the July 8 and 16 peaks, but it could not accurately model the July 30 peak with its large amount of flow on the floodplain, since the floodplain was modeled as storage cells that allowed for some flow but not for active flow areas where significant velocities could exist. The small increase in stage for a significant increase in flow tends to confirm modeling done for the reach from Waverly to Jefferson City on the Missouri River (Hall, 1991). Hall found that once significantly overtopped, levees had little impact on flood stages as water began to flow downstream over them.

Table 8.3 Stage and discharge values for three flood peaks at Hermann, Missouri, for 1993 flood showing large increase in flow for minor increases in stage due to increasing flow on floodplain.

DATE	STAGE FEET	FLOW CFS	CONDITION
8 July	35.0	418,000	Levees intact
16 July	34.8	506,000	Floodplain flow starting, acting as network of storage cells
30 July	36.3	750,000	Floodplain actively conveying flow

The 1973 and 1986 Flood Events

The model was calibrated to the 1973 and 1986 floods and the options evaluated for those floods as a means to estimate the effects of the levees for lesser flood events. The 1973 flood corresponds to about a 40-year event on the Mississippi River and a minor event on both the Illinois and Missouri Rivers. The 1986 flood event was about a 50-year event on the Missouri River and about a 10-year event on the Mississippi River above the confluence with the Missouri. The relationship between peak daily flows for the three floods at various locations is shown in table 8.4.

Table 8.4 Maximum daily flows in cfs at various river gaging stations for the 1973, 1986, and 1993 floods. The Hermann gage is located on the Missouri River at RM 97.1 and the Alton / Grafton gage is located on the Mississippi River above the Confluence of the Missouri and Mississippi Rivers.

GAGING STATION	1973 Flood	1986 Flood	1993 Flood
Hermann	489,000	519,000	739,000
Alton / Grafton	527,000	307,000	596,000
St. Louis	851,000	721,000	1,080,000
Chester	885,000	744,000	1,000,000

It should be noted that the maximum stage of a flood is affected by the season in which the flood occurs. This is due to a temperature effect on the bedforms and associated hydraulic roughness (Manning's "n" value) for the channel. An example of temperature effect occurred during the 1973 flood at St. Louis when a flow of 400,000 cfs produced stages that differed by 6 feet.

The Manning's equation is an empirical representation of the factors affecting flow in a channel. It accounts for the hydraulic roughness of the channel by an "n" value which has been related to vegetation and bed material for a wide range of conditions. It also considers channel slope and hydraulic radius (area of flow divided by wetted perimeter of the channel) to calculate velocity in the channel.

Hydraulic Roughness Coefficients

For the no-agricultural-levee analysis, the determination of the proper hydraulic roughness coefficient or Manning's "n" value became critically important. Although data exist from the late 1800's describing the type of floodplain that existed at that time, the data may or may not be indicative of the floodplain that would exist today without the levee system. The data are, however, probably more indicative of the natural floodplain that existed prior to European settlement than current conditions. It is also difficult to predict the land cover that would exist for a condition with no agricultural levees, since continued farming would be expected on the floodplain in conjunction with bottomland forests, shrubs, wetlands, and grass prairies. For this reason, a range of Manning's "n" values was tested for the floodplain. The areas that are currently inside the levees were modeled using the same "n" values that were used during calibration, and only the "n" values behind the existing levees were adjusted. The Manning's "n" values used for calibration were selected to reproduce observed water surface elevations along the river. A range of "n" values was used when analyses were conducted using the UNET model. Values for "n" varied from 0.040 (unrealistically low for long reaches of the floodplain) to values that were clearly too high for long reaches of the floodplain, such as 0.640 and 0.999 (a value which allowed storage only and no conveyance). The Manning's "n" values used in the study and the descriptors applied by Dr. Barkau are shown in table 8.5

Table 8.5 Manning's "n" values and associated land cover descriptions used by Barkau to test effects of floodplain hydraulic resistance on flood stage for no-levee option.

Manning's "n" Value	Descriptor
0.040	Grass Meadow
0.080	Harvested Corn Field
0.160	Corn Field
0.320	Forest
0.640	Dense Forest
9999.0	No Overbank Conveyance

The value associated with a corn field corresponds well with values obtained by the USDA-ARS (Ree and Crowe, 1977) for sorghum which shows values as high as 0.140 for deep flow (90 percent submergence) through mature sorghum. For the sorghum tested by the ARS, "n" values varied from 0.047 to 0.142 depending on the depth of flow and the rate of flow. Values for forest and dense forest appear high in view of a USGS report (Arcement and Schneider, 1989) which shows the highest values for forest at about 0.20. It should be noted, however, that the flow depth through the denser forests listed in the USGS publication is between 2.6 and 5 feet and "n" values have been shown to vary with depth for crops (Ree and Crowe, 1977) and can be assumed to do so for forests as well. It may be that typical floodplain forests have a "n" value more on the order of 0.160 to 0.200 for relatively shallow flows, but when flow reaches the limbs of trees, the "n" value should increase. This would result in varying flow vertically through the water profile, a condition that cannot be evaluated by the UNET model.

The ARS conducted extensive testing on the Manning's "n" values of agricultural crops but similar in-depth testing has not been done for shrubs and trees. Currently, research is underway at Utah State University under a contract with the USACE Waterways Experiment Station to determine the Manning's "n" values for submerged shrubs, and future work is planned for trees. This work will help determine better "n" values to use for shrubs and trees when flood depths are not similar to those presented in the 1989 USGS report.

Recommendation 8.5: Since the Manning's "n" value is not well understood for shrubs and especially not for deep flows through trees, additional research should be undertaken or continued to determine proper "n" values for use with shrubs and trees during deep flooding. The relationship between various depths of flow and Manning's "n" values should be determined for urban and suburban land covers as well.

In addition, the selection of the proper "n" value is affected by the model being used, the experience of the modeler, the number of inaccuracies in the model (cross-sections, land cover), and other factors. In effect, the selection of the "n" value for a reach of river is determined by how the model calibrates to the observed water surface and becomes the final device for tuning the model to give accurate results.

No-Agricultural-Levee Results

After the model was calibrated to the 1993 flood, the agricultural levees were eliminated from the model to estimate the effects of the levees. Since the precise Manning's "n" value is unknown, a range of values was used to encompass the entire range possible. The lowest value used was 0.040. This value would assume that the entire floodplain was grass meadow or farmland with short crops. If the floodplain included corn, rows of trees, or other obstructions (such as breached levees), the "n" value would be higher.

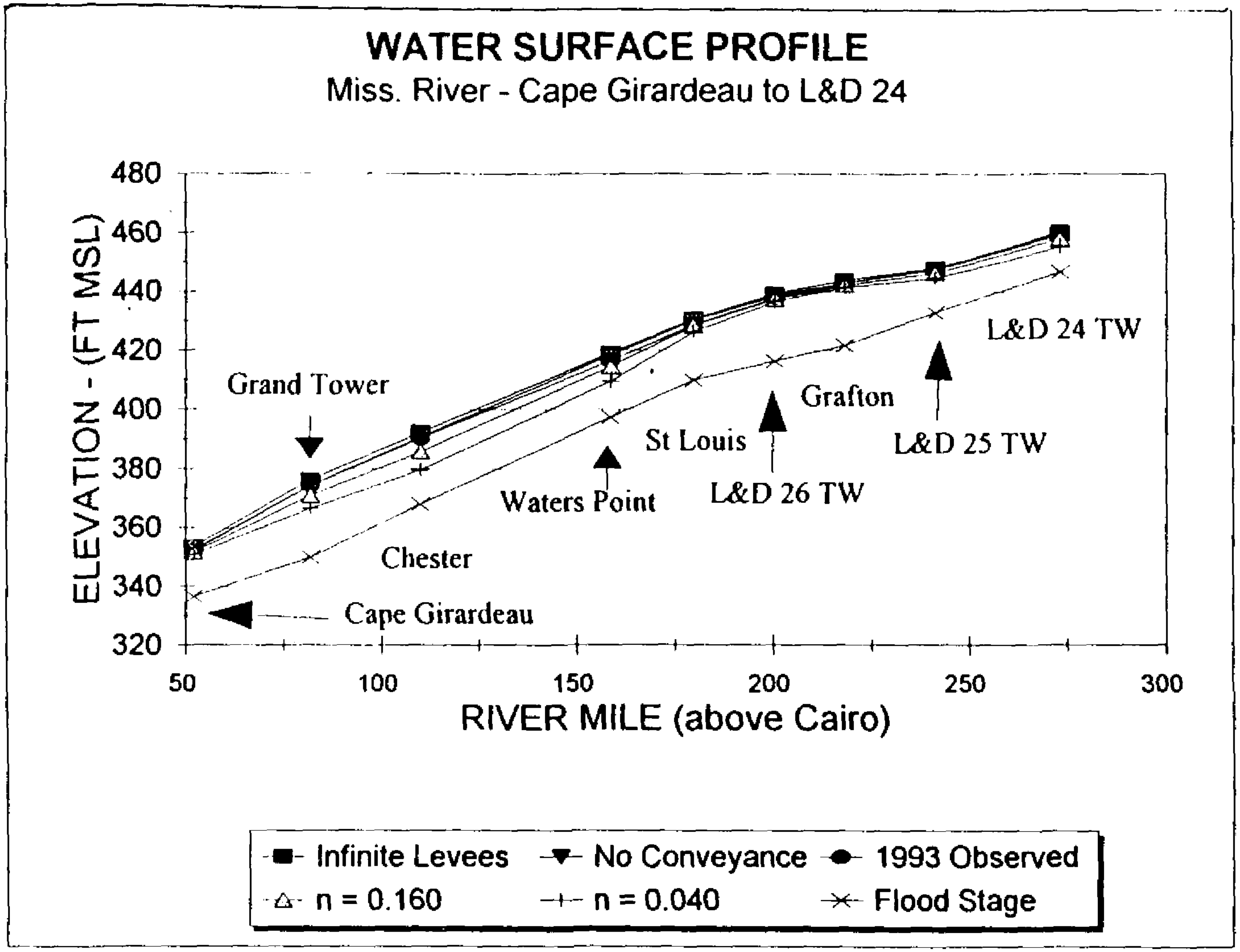
The other extreme was a condition where no flow was allowed on the floodplain, and the floodplain was used only for the storage of water associated with the flood (no-conveyance scenario with "n" = 9999). The use of a number of "n" values in between the two extremes shows how the stages vary with the resistance of the floodplain to flow.

Water surface profiles for the no-agricultural-levee condition are shown in figure 8.4 for the Mississippi River portion of the model. The results clearly indicate a trend of increasing flood stage with increasing "n" values, as can be seen in table 8.6. Results on the Illinois and Missouri Rivers showed similar trends - increasing flood depth with increasing "n" values (increasing resistance to flow). The changes in water surface elevations for most of the river gaging stations used in the model study are presented in table 8.6. Negative numbers indicate stage reductions, and positive numbers indicate increases in stage with respect to observed 1993 flood elevations.

The maximum stage reduction for the 0.040 condition was 10.7 feet at Chester, Illinois (river mile 109.9). It can be seen in figure 8.4 that there is a change in slope in the flood profile at about Waters Point (river mile 158.5) for all conditions and for flood stage. The reason for the large reduction in stage at Chester appears to be the wide floodplain and the increased slope of the profile in this area as compared to areas upstream. As can be seen from table 8.6 and figure 8.4, this large reduction in stage is only at Chester for the section of the river modeled and cannot be extrapolated to other locations in the Upper Mississippi River Basin without modeling the specific reach of the river. Foster and Allen (1975) found that reductions in flood stage similar to those obtained for the no levee condition with low "n" values (0.080) could also be obtained by removal of trees from the area between the riverbanks and the existing levees on the Mississippi River between St. Louis and Cape Girardeau. This finding further demonstrates the effect of large mature trees can have on flood profiles. However, trees are useful in reducing the energy of flood flows, thus providing some protection for the levees.

It can be seen that with a Manning's "n" value between 0.320 and 0.640, there is very little change from the observed 1993 flood elevations. This indicates that if the levees were eliminated and the entire floodplain became dense forest with underbrush, (assuming these "n" values are correct for these land covers), flood stages would be similar to those observed for the 1993 flood in the section of the river modeled. It is highly unlikely that the entire floodplain would be covered with dense forest and underbrush, since indications are that there were mixed land cover types during pre-settlement times. If the levees were eliminated and a mix of farming, wetlands, grass prairie, and forest were to be established on the floodplain, some

Figure 8.4



WATER SURFACE PROFILE
Miss. River - Cape Girardeau to L&D 24
ELEVATION - (FT MSL)
480
460
440
420
400
380
360
340
320
50
100
150
200
250
300
RIVER MILE (above Cairo)
Grand Tower
Chester
Cape Girardeau
Waters Point
St Louis
L&D 26 TW
Grafton
L&D 25 TW
L&D 24 TW
Infinite Levees
No Conveyance
1993 Observed
n = 0.160
n = 0.040
Flood Stage

Table 8.6 MAXIMUM STAGE DIFFERENCES FROM OBSERVED 1993 FLOOD

RIVER GAGE	INFINITE LEVEES	NO LEVEES					
		Manning's "n" Value Used to Model Floodplain					
MISSISSIPPI RIVER	*Infinitely High and Strong Levees*	0.040	0.080	0.160	0.320	0.640	9999 (No Conveyance)
L & D 24 TW	0.1	-4.3	-2.6	-1.4	-0.5	0.1	0.7
L & D 25 TW	0.6	-2.9	-1.9	-1.1	-1.1	-0.2	0.3
GRAFTON	1.0	-1.4	-1	-0.6	-0.4	-0.2	0
L & D 26 TW	1.3	-1.2	-0.8	-0.4	-0.1	0.2	0.5
ST. LOUIS	1.9	-2.5	-1.5	-0.5	0.2	0.7	1.4
WATERS POINT	2.7	-6.8	-4.1	-1.8	-0.3	0.7	1.9
CHESTER	2.1	-10.7	-7.3	-4.5	-2.5	-1.2	0.5
GRAND TOWER	2.1	-7.8	-5.3	-3.3	-1.9	-0.1	0.1
CAPE GIRARDEAU	1.4	-1.3	-0.9	-0.5	-0.1	0.1	0.4
ILLINOIS RIVER							
VALLEY CITY	0.3	-1.1	-0.7	-0.3	-0.1	0.1	0.3
HARDIN	1.1	-1.2	-0.8	-0.5	-0.2	-0.1	0.2
MISSOURI RIVER							
HERMANN	0.2	-4.5	-2.8	-1.6	-0.7	-0.2	0.4
NEW HAVEN	0.4	-4.1	-2.4	-1	-0.1	0.5	1.1
WASHINGTON	0.5	-4.7	-3	-1.6	-0.6	0.1	0.8

reduction in stage would occur depending on the land cover mix and the location of different land uses and covers in the floodplain. These results also show the high degree of dependence between the stage-flow relationship of a river and vegetation on the floodplain. This dependence is sometimes demonstrated by comparison of winter and summer floods when the amount and density of floodplain vegetation is significantly different and similar flood flows may create flood stages that differ by several feet. Changes in water temperature between seasons also affect the shape of channel bedforms in rivers like the Mississippi and Missouri. This change in shape also results in a change in roughness and can change the stage of a given flood by several feet. When both factors - vegetation and bedform - combine, a flood stage may vary by several feet at a gage like St. Louis for identical flow rates in differing seasons (Barkau, 1994; Burke, 1966).

The probability of "n" values of either 0.040 (grass meadow) or of 0.640 (dense forest) and 9999 (no conveyance) occurring for long reaches of the floodplain is low, and values in the mid-range should be used in any likely scenario.

No Levee Failure or Overtopping Results

The option to model no levee failures or overtopping assumed that infinitely high and strong levees were in place at existing levee locations. The results of this study for the 1993 flood are also shown in table 8.6. The largest increases in stage occurred at Waters Point (2.7 feet), with Chester and Grand Tower both indicating a stage increase of 2.1 feet over the observed 1993 flood. All of these locations were impacted by the Columbia and Harrisonville levee failures at the peak of the flood. The UNET simulation indicates that the failure of the Harrisonville and Columbia levees at a critical time just preceding the peak of the flood lowered the peak at St. Louis and Waters Point by about 1.9 feet. This peak reduction was due to the large amount of water drawn into the levee systems. If the levees had failed earlier in the flood, the storage would have been filled and the flood would have peaked at or near the higher stage.

In other locations, the differences were all less than 2 feet in additional depth for the no-levee-failure option. The maximum reductions in stage occurred downstream of the levee breaks, and the effects carried a relatively long distance down the river for the Harrisonville and Columbia failures since they occurred just prior to the peak of the flood. This study does not account for what might have happened in the study reach if no upstream levees had failed during the 1993 flood; it only accounts for the portion of the river modeled.

Pick-Sloan Floodway Results

The original Pick-Sloan plan recommended a floodway varying in width from 3,000 to 5,000 feet for the portion of the Missouri River below Gavins Point Dam. The recommended floodway width in the portion of the river being modeled was 5,000 feet. The Pick-Sloan floodway has been implemented only where Federal levees have been built --- primarily above Kansas City. The SAST evaluated the effects this option might have had on the flood of 1993. Although the reach of the Missouri River modeled is short, with only 3 gages along this section of the river, it can give some indication of what might happen if the floodway were to be implemented. The floodplain width in the reach modeled is also much narrower than the width above Glasgow. Above Glasgow, the average width is 6.5 miles, while in the Fulton quadrangle (within the area modeled) the average floodplain width is 1.9 miles. Given this difference in width, the results for the Missouri River portion of the model should be used only for the portion of the river modeled and not extended outside that area.

Additional modeling of the entire reach of the Missouri River below Gavins Point would be necessary to reach any definite conclusions. The gage at Hermann is also at the inflow section of the model, and model results at this location probably are not completely accurate. Only gages at New Haven, Washington, and St. Charles may be used for reference. St. Charles results were not summarized by Dr. Barkau, since they are highly affected by the dynamics of the Missouri River - Mississippi River crossover at high flows.

The results show that the floodway with low "n" values lowers the stage on the Missouri River, but causes slight rises on the middle Mississippi River (less than 0.5 ft) due to increased conveyance on the Missouri River. For high "n" values in the Pick-Sloan floodway, the stage is about the same on the Missouri River but slightly lower on the middle Mississippi River. Dr. Barkau states, however, that "given the accuracy of the model, the model shows that the Mississippi and Illinois Rivers are essentially unchanged by the Pick-Sloan Floodway" - at least for the portion of the floodway that was modeled.

Hypothetical Floodway Results

A hypothetical floodway was developed by the SAST for the portion of the Missouri River that was modeled with the UNET model. The floodway was an attempt to approximate the pre-navigation-project active channel widths. This approximation involved comparing the 1879 river alignment and widths with current alignment and widths. This option produced no significant changes over the Pick-Sloan floodway for the reach of the river modeled.

1973 and 1986 Floods

Comparative results for selected gaging stations for the 1993, 1973, and 1986 floods are shown in table 8.7 for the no-levee analysis. The trends for the 1993 flood also hold for the

Table 8.7

		CALCULATED STAGE CHANGES FROM OBSERVED 1993, 1973, AND 1986 FLOODS IN FEET						
		INFINITE LEVEES	NO LEVEES					
RIVER GAGE	YEAR	Infinitely High and	Manning's "n" Value Used to Model Floodplain					
		Strong Levees	0.040	0.080	0.160	0.320	0.640	9999
MISSISSIPPI RIVER								(No Conveyance)
GRAFTON	93	1.0	-1.4	-1.0	-0.6	-0.4	-0.2	0
	73	1.3	-0.9	-0.8	-0.8	-0.7	-0.6	-0.7
	86	0.7	-0.4	-0.3	-0.3	-0.2	-0.2	-0.3
ST. LOUIS	93	1.9	-2.5	-1.5	-0.5	0.2	0.7	1.4
	73	1.5	-2.7	-2.0	-1.5	-1.2	-1.0	-0.8
	86	1.0	-1.3	-0.8	-0.4	-0.1	0.0	0.2
CHESTER	93	2.1	-10.7	-7.3	-4.5	-2.5	-1.2	0.5
	73	1.5	-8.0	-5.7	-3.9	-2.7	-2.0	-1.2
	86	0.7	-5.2	-3.4	-1.9	-1.0	-0.4	0.1
GRAND TOWER	93	2.1	-7.8	-5.3	-3.3	-1.9	-1.0	0.1
	73	1.2	-6.4	-4.7	-3.5	-2.7	-2.2	-1.7
	86	0.7	-4.5	-3.2	-2.3	-1.6	-1.3	-1
ILLINOIS RIVER								
HARDIN	93	1.1	-1.2	-0.8	-0.5	-0.2	-0.1	0.2
	73	1.2	-0.8	-0.6	-0.7	-0.5	-0.5	-0.5
	86	0.6	-0.3	-0.2	-0.1	-0.1	-0.1	-0.1
MISSOURI RIVER								
WASHINGTON	93	0.5	-4.7	-3.0	-1.6	-0.6	0.1	0.8
	73	0.0	-2.6	-1.6	-0.9	-0.4	-0.2	0.1
	86	0.3	-3.5	-2.4	-1.4	-0.8	-0.4	0.1

lesser floods but to a lesser degree, as would be expected since the floods are smaller. Values for the floodways also hold similar trends (not shown) as do the no-levee-failure (infinitely high levees in table 8.7) tests.

In viewing the results in table 8.7, it should be noted that the 1973 flood was about a 40-year event on the Mississippi River but a minor event on the Missouri, while the 1986 flood was a 50-year event on the Missouri but only a 10-year event on the Mississippi River. For the Missouri River data to be consistent with the presentation, the floods should be reordered to be 1993, 1986, and 1973 to follow from greatest flood to least flood for the Mississippi River results in table 8.7.

The results for Grafton and Hardin show similar trends, with the high "n" value no-levee conditions showing higher reductions for the 1973 flood than for the other floods, but the stations are in relatively close proximity and would be expected to show similar results. The stations show similar reductions overall, with the maximum reduction being 1.4 feet for the 0.040 "n" value condition and 1 foot or less for all other conditions.

CONCLUSIONS

The effect of levees on flood stage varies according to characteristics of the river at each station modeled. The effects are also highly dependent on the type of vegetation assumed for the floodplain. For the most severe and highly unlikely scenario, a grass meadow floodplain, stages were reduced by 10.7 feet at the Chester station and 2.5 feet at St. Louis for the 1993 flood.

Using a more probable mixture of crops, forest, and wetlands ("n" = 0.080 to 0.320), the maximum flood depth increases due to the levees ranged from as much as 2.5 to 7.3 feet at Chester to as little as 0.1 to 0.8 feet at lock and dam 26, depending on the hydraulic roughness of the assumed floodplain. Changes at St. Louis for this range of "n" values are an increase of 0.2 feet for an "n" of 0.320 to a reduction of 1.5 feet for an "n" of 0.080. Flood depths without levees would still be in the range of 11 to 18 feet deep at Chester and 16 to 21 feet deep at Grand Tower for "n" values of 0.080 to 0.320.

While the importance of the levee effects has been and will continue to be debated, results of this study indicate that nearly all of the levees of significant size upstream from the area modeled filled with water due to overtopping or failure. The fact that water filled most leveed areas, but flooding still increased indicates that for a flood of the magnitude and duration of the 1993 flood, levees had little system-wide impact, while locally, where failures resulted in concentrated flows, high velocities, and associated damages, overtopping or breaching of the levees often produced major effects. As the areas protected by levees filled, they produced only a temporary effect on upstream and downstream flood stages and heights that were quickly overcome by the flood. The duration and amount of this temporary reduction in stage is proportional to the area protected by the levee and the number and size of levee breaches or length of overtopping. The Harrisonville and Columbia failures had significant effects in stage reduction only because of the timing of the failure. Had these districts failed at an earlier time in the flood, the effect would also have been only temporary due to the massive volume of water in the flood.

The UNET studies show that as the floodplain storage increased due to higher stages and increased resistance to flow on the floodplain, the flood peak downstream was reduced. Since the levees provided a higher resistance to flow than would have been associated with the current condition of the floodplain, storage should have increased slightly - possibly enough to approximate a more natural floodplain condition. Higher resistance would tend to maximize storage in the levee districts and provide a reduction of downstream flow more like to what might have occurred under natural conditions. This possibility, however, would need to be verified by a detailed modeling effort.

The use of floodways, while beneficial for the local areas, could have beneficial or detrimental effects upstream and downstream and should be modeled using a model of the whole river section involved - that is, the lower Missouri River for significant projects along the Missouri. The need for additional modeling is due to changes in the speed with which water moves down the floodway (faster for lower "n" values), the timing of flood peaks, and the effect of timing downstream from the project.

The development of new mathematical models for the entire lower Missouri for each individual project is very costly and could not be accomplished. It would be more practical to develop a standard set of cross-sections that would be available to modelers for the rivers in the Upper Mississippi River Basin. If these cross-sections were readily available, a mechanism could be developed for updating the set and, as local changes are made, the information could be incorporated into the master set, thus providing an up-to-date set of cross-sections for modeling efforts.

Recommendation 8.6: Develop a standard set of cross-sections that can be updated by local, state, and Federal input for the modeling of long river reaches. The availability of a standard set would reduce the cost of modeling and facilitate the development and calibration of a basin-wide model that could be used for planning, design, operations, and forecasting if necessary. The standard cross-sections must be updated when there are changes in floodplain morphology and must be available through the clearinghouse.

The UNET model is a one-dimensional model which assumes a water surface that is level across the river. For problems where the direction of flow is not directly down the channel, a two-dimensional model should be used if the direction and velocity of the water in the junction are important. An example of such a junction is at the confluence of the Mississippi and Missouri Rivers. The use of the two-dimensional model at river junctions and at areas around critical infrastructure is recommended for more accurate representation of flow and velocity data. The two-dimensional models should be developed such that they can be coupled to the one-dimensional model for boundary conditions. To address the impacts of complex land use patterns on the floodplain, two-dimensional models are needed.

Recommendation 8.7: For the short term, develop a model capable of handling 1-dimensional and 2-dimensional modeling simultaneously such that two-dimensional segments can be set into one dimensional reaches, or develop full two-dimensional modeling capabilities for the entire river reaches with the capability to model levee breaches, river junctions, and areas with critical infrastructure to determine flow directions and velocities. For the long term, extend the two dimensional capabilities to the entire floodplain.

One of the major limiting factors in the development of a two-dimensional hydraulic model is the lack of sufficiently accurate digital elevation model (DEM) data. Initial estimates indicate that a DEM with a vertical accuracy of 0.3 to 1 meter root mean square error (RMSE) and a horizontal post spacing of 10 meters would be sufficiently accurate to develop a two-dimensional hydraulic model of the floodplain. This DEM would facilitate the use of two-dimensional models which can more accurately predict flow at river confluences such as the Missouri, Illinois, and Mississippi confluence where flows and distributions are complex. Two-dimensional models would also be of value in modeling levee breaches and overtoppings and more accurately modeling flows near breaches.

Recommendation 8.8: Acquire digital elevation data of sufficient vertical accuracy and horizontal resolution to support development of a two-dimensional hydraulic model of the floodplains of the upper Mississippi, lower Missouri, and Illinois Rivers.

There are several methods of acquiring DEM data. The methods include standard photogrammetry, conversion of existing topographic data, or using new technologies such as radar interferometry or laser elevation measuring. The new technologies are still in development and expensive but may reduce the cost of obtaining high resolution elevation data once they are proven and made operational.

Recommendation 8.9: Continue investigating new methods for acquiring topographic data and their associated costs by testing the various technologies to determine which is most technically and economically effective.

For sophisticated modeling of the floodplain to be effective, accurate land cover data are necessary. These data will be used to determine the Manning number for the portions of the floodplain being modeled. These data should be acquired using a standard land cover classification scheme. A cooperative activity among the states, tribal, and Federal government should be used to acquire, update, and distribute these data through the clearinghouse.

Recommendation 8.10: The USGS in cooperation with USDA, EPA, and the states and tribal governments should acquire detailed land use data to support modeling on the floodplain.

CHAPTER 9

ECONOMIC DATA AND ANALYSIS

INTRODUCTION

It became clear in early discussions within the SAST and with external advisors that combining economic data and analysis with scientific data and analysis would provide policy makers and managers with a more powerful suite of information on which to base decisions. However, the economic data collected and the analysis conducted were limited by three factors: (1) agencies were only able to provide one economist to the team, (2) the economist was provided to the team only two weeks before the initial intensive portion of the SAST activity was completed, and (3) the emphasis for economic data acquisition was primarily on agricultural economic data.

This chapter describes some of the economic data in the SAST database and provides some cursory analysis with those data. There are additional discussions of some useful analyses that could be conducted to aid policy makers and managers.

AGRICULTURAL ECONOMICS

Excessive soil moisture and flooding caused serious economic and infrastructure losses across the study area. Most agricultural damage was due to high rainfall and wet soils --- not to actual inundation by floodwater. A related point is that most damage took the form of one-year crop/income losses rather than longer-term cropland damage due to scouring or deposition. These points highlight the variety of policy responses that need to be considered in different areas --- from annual crop/revenue insurance and disaster assistance to longer-term fish and wildlife habitat restoration or cropland restoration and levee repair. Total flood and other related damages are estimated in the 10 billion to 16 billion dollar range (Benjamin, 1994). Total Federal expenditures in response to the flood are over 5.4 billion dollars to date (USDA updates, June 15, 1994) and still increasing.

Hydric soils indicate the previous existence of wetlands that have subsequently been converted to agricultural use. This makes them attractive for crop production in most years, but vulnerable to occasional wet years. Various programs attempt to deal with the tradeoff between the private profitability of wetland conversion for crop production and the public costs associated with wetland conversion, especially during events like 1993's weather and flooding. Swampbuster provisions in the 1985 farm bill imposed penalties for conversion of wetlands to agricultural production. The CRP, also established in the 1985 farm bill, allowed retirement of wetlands for 10 years. The WRP, established in the 1990 farm bill, allowed restoration and permanent retirement of prior-converted wetlands.

Five hundred thirty-two counties in nine states received disaster-designation with the flood of 1993. Twenty-five million people and 14.7 million jobs are located in these counties (Benjamin, 1994). Most of this population was impacted by the flood in one way or another, from flooded basements to lost homes, blocked transportation routes, or time spent volunteering for flood relief. Table 9.1 shows the extent of the disaster. It includes the number of disaster-designated counties by state as of March, 1994. Some of these counties are also receiving 1994 disaster designations as a result of 1994 rainfall on soils that were still saturated from the 1993 rains.

Table 9.1

State	Designated Counties (number)	Share of all Counties (percent)	Population (million)	Employment (million)
Illinois	39	38	7.5	4.3
Iowa	99	100	2.8	1.6
Kansas	57	54	1.9	1.1
Minnesota	57	66	2.1	1.1
Missouri	103	90	4.8	2.9
Nebraska	52	56	1.3	0.8
North Dakota	39	74	0.5	0.3
South Dakota	39	59	0.5	0.3
Wisconsin	47	65	3.7	2.2
Total	532	67	25.1	14.6

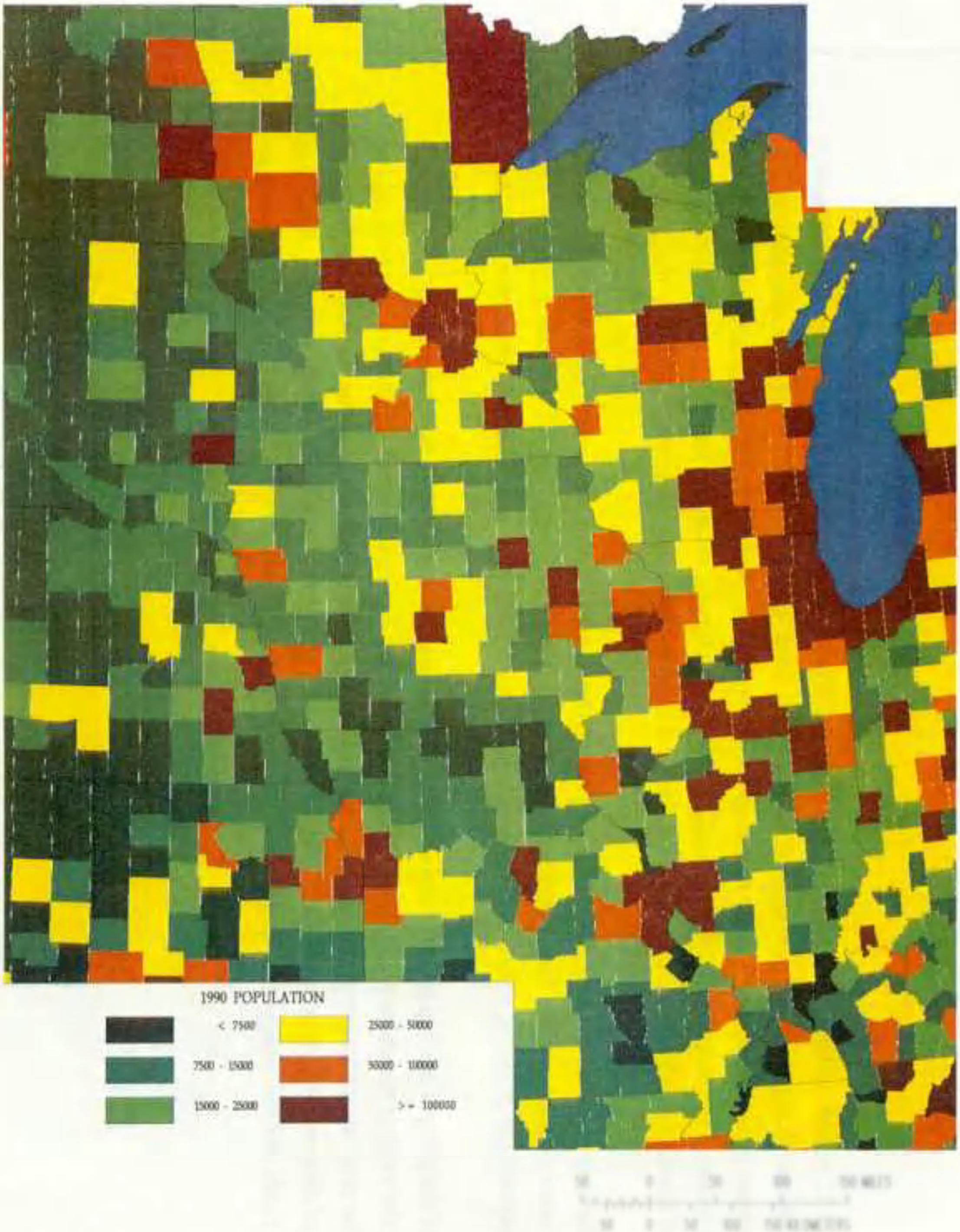


Figure 9.1 shows the 1990 population of the area by county. Most of the urban counties in this region are located directly on the Mississippi or Missouri River. All of the remaining medium-size towns are located directly along floodplains of major tributaries, such as the Illinois, Des Moines, Cedar, and Big Sioux Rivers. The SAST database contains both county and block census data.

Agricultural Damages

Seventy percent or $2 billion dollars of the $2.85 billion in total USDA flood disaster payments went to the prairie pothole counties of the Dakotas, Minnesota, Wisconsin, and north central Iowa. Eighty percent of the crop insurance and seventy percent of the disaster program payments went to this mostly upland area. Minnesota had the largest number of non-harvested crop acres and received the largest USDA payments. Iowa had the largest crop and income losses. Missouri had the greatest percentage of flooded cropland. Table 9.2 shows the total USDA emergency assistance paid after the 1993 flood as of June 13, 1994.

The majority of the crop loss and the majority of the USDA'payments went to farmers whose fields were too wet to plant or so wet that they were planted too late for a good harvest. Comparison of figures 4.8 and 9.2 shows a visual correlation between the percentage of hydric soils in counties and the amount of crop disaster and crop insurance paid, and crop production losses.

An examination of the pattern of crop disaster and crop insurance claims after the 1993 flood shows the complex interrelationships among the various agricultural assistance programs (table 9.2). For instance, the disaster program paid out sixty percent more than the crop insurance program. Only North Dakota had greater insurance payments than disaster payments. The amount of disaster payments in Missouri was five times the amount of crop insurance payments. Additional ASCS, SCS, and FmHA funds are still being spent in the ongoing repair work. Final USDA payments will come close to three billion dollars.

Table 9.2 USDA emergency assistance paid to flood states in millions of dollars

State	Disaster Assistance (ASCS)	Crop Insurance Indemnities (FCIC)	Emergency Conservation Program (ASCS)	Emergency Program EWP & EWRP (SCS)	Emegency Food Stamps and Commodities Provided (FNS)	Business and Industry Loans (RDA)	Rural Housing and Farm Program Loans & Grants (FmHA)	Total
Illinois	55.3	25.6	0.46	15.12	2.1	0.59	3.61	102.8
Iowa	396.4	282.5	2.9	36.1	2.4	6.7	32.1	759.1
Kansas	71.1	40.5	0.1	8.0	0.0	1.2	0.7	121.7
Minnesota	481.3	354.2	0.1	2.0	0.0	0.0	10.8	848.5
Missouri	128.7	27.8	1.6	35.0	6.4	0.7	4.9	205.1
Nebraska	85.9	49.1	0.4	2.1	0.0	0.1	0.4	138.0
North Dakota	119.0	139.5	0.0	1.3	0.0	0.0	0.8	260.5
South Dakota	163.2	54.3	0.3	8.3	0.0	0.6	2.1	228.8
Wisocnsin	141.2	47.0	0.0	1.3	0.0	0.0	4.2	193.7
TOTAL	**1642.1**	**1020.5**	**5.9**	**109.3**	**10.9**	**9.9**	**59.6**	**2858.2**

Table 9.3 shows corn, soybean, and total principal crops planted in 1993 but not harvested. The greatest amount of non-harvested corn acreage was in Minnesota, Iowa, and Wisconsin, due more to the shortened, cool growing season and wetland ponding than to direct floodplain flooding. There was a 600,000-acre or 20 percent increase in the silage harvest in these nine states as farmers cut corn that was too slow to make grain. Some counties, particularly in Iowa, had double their normal silage harvest. There was also a 280,000-acre increase in hay-harvested from 1992 to 1993 in Iowa and Illinois due mostly to CRP land being opened for harvesting with the disaster declarations.

There were two million acres of corn and soybeans intended to be planted and harvested for grain according to the early-June 1993 National Agricultural Statistics Service (NASS) crop survey, that did not get planted. This loss is in addition to the acreage loss shown in table 9.3. This included 680,000 acres in South Dakota, 450,000 acres in Iowa, 375,000 acres in Minnesota, and 192,000 acres in Wisconsin, primarily in the pothole region. These losses were due to the wet spring and early summer weather that prevented planting on wetter fields.

Iowa and Illinois have comparable total acres of cropland and comparable amounts of non-harvested acres in 1993. Illinois losses were concentrated along the Mississippi floodplains and the Wisconsin border, with the rest of Illinois producing well. Iowa losses were spread more evenly. Missouri lost 270,000 acres of corn (12 percent) and 650,000 acres of soybeans (15 percent) mainly to direct flooding. Less than 30 percent of the lost acreage and production was due to direct flooding in the river valleys. However, three quarters of the ASCS Emergency Conservation Program and SCS Emergency Watershed Program funds were expended in the floodplains.

Table 9.3 Crop acres planted but not harvested in 1993.

Acres planted but not harvested in 1,000 acres						
State	Total corn acres[1] not harvested	Percent not harvested / planted	Soybean acres not harvested	Percent not harvested / planted	All principal crops: acres not harvested	All principal crops: percent not harvested / planted
Illinois	380	4%	400	4%	1391	6%
Iowa	600	5%	300	4%	1646	7%
Kansas	70	4%	100	5%	1415	6%
Minnesota	925	15%	400	7%	2337	12%
Missouri	270	12%	650	15%	1284	1%
Nebraska	150	2%	60	1%	2150	1%
North Dakota	95	12%	60	1%	2150	1%
South Dakota	330	1%	100	6%	1158	8%
Wisconsin	500	13%	30	5%	518	6%
Nine State TOTAL	3320	7%	2140	6%	12715	8%
TOTAL USA	3486	5%	2908	5%	24358	8%

Crop Production, 1993 Summary, NASS/USDA, January 1994.
[1]Include both grain and silage.

Crop Production Losses

Table 9.4 shows the 1988 to 1993 corn production for the nation, for the nine state region, and for four states in the flooded area. Note that while corn production was down sharply in Iowa, Minnesota, and Missouri, corn production in Illinois and Kansas was down only 20 percent from 1992 and actually above the five-year average.

Table 9.4
Corn production by state in millions of bushels

State	1988	1989	1990	1991	1992	1993	1988 to 1992 avg.	1993 % of 88-92 avg.	1993 minus 88-92 avg.	1993 as % of 1992	1993 minus 1992
Illinois	701	1,322	1,321	1,177	1,646	1,300	1,233	105%	67	79%	-346
Iowa	899	1,446	1,562	1,427	1,904	880	1,448	61%	(568)	46%	-1024
Kansas	144	155	189	206	260	216	191	113%	25	83%	-44
Minnesota	348	700	763	720	741	322	654	49%	(332)	43%	-419
Missouri	154	220	206	312	423	167	263	63%	(96)	39%	-256
Nebraska	818	847	934	991	1,067	785	931	84%	(146)	74%	-282
North Dakota	22	35	37	51	37	16	36	44%	(20)	43%	-21
South Dakota	132	191	234	241	277	161	215	75%	(54)	58%	-116
Wisconsin	131	311	354	381	307	216	297	73%	(81)	70%	-91
Nine state total	3,349	5,227	5,600	5,506	6,662	4,063	5,269	77%	(1,206)	61%	-2725
Total USA	4,929	7,525	7,934	7,475	9,482	6,344	7,469	85%	(1,125)	67%	-3138
Percent of USA	68%	69%	71%	74%	70%	64%					

USDA-NASS, Crop Production 1993 Summary, 1994.
USDA-NASS, Crop Production 1991 Summary, 1992.
USDA-NASS, Crop Production 1990 Summary, 1991.

Value of Production

Major reductions in crop production typically result in higher crop prices. Farmers able to harvest a crop will thus be compensated at least in part for their losses by earning a higher price on the portion of the crop sold, while those suffering little or no damge will frequently be unambiguously better off. Table 9.5 shows the value of crop production in 1993 exceeded the average for 1987-91 and was only slightly lower than in 1992, indicating that the farm economy of the region as a whole suffered relatively little. Only in Iowa, Minnesota, and Missouri did the value of production fall substantially.

Table 9.5

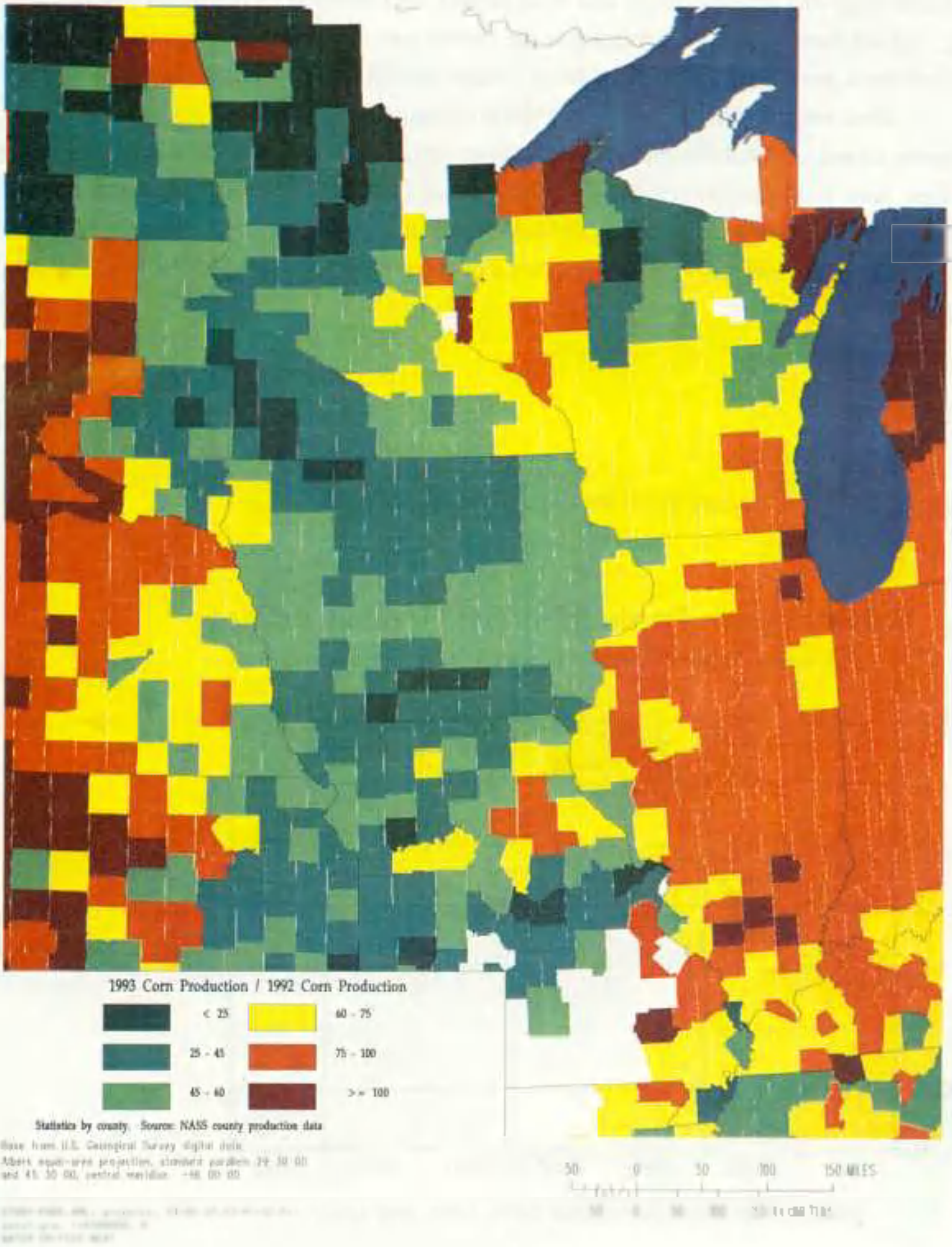
Value of production for field and miscellaneous crops, in millions of dollars

State	1987	1988	1989	1990	1991	1992	1993	1987-91 Avg	1993 as % of 87-91	1993 minus 87-91 avg.	1993 as % of 1992	1993 minus 1992
Illinois	4,775	4,199	5,979	5,753	5,283	6,359	6,485	5,198	125%	(1,287)	102%	(126)
Iowa	4,901	4,628	5,760	5,812	5,627	6,342	4,220	5,346	79%	1,126	67%	2,122
Kansas	2,341	2,771	2,234	2,609	2,481	2,950	2,966	2,487	119%	(479)	101%	(16)
Minnesota	3,595	3,079	4,089	4,084	3,911	3,957	2,783	3,752	74%	969	70%	1,174
Missouri	2,026	2,124	2,242	2,073	2,107	2,556	2,040	2,114	96%	74	80%	516
Nebraska	2,881	3,661	3,420	3,621	3,667	3,732	3,586	3,450	104%	(136)	96%	146
North Dakota	1,926	1,301	1,843	2,082	2,188	2,649	2,404	1,868	129%	(536)	91%	245
South Dakota	1,408	1,158	1,434	1,638	1,611	1,825	1,638	1,450	113%	(188)	90%	187
Wisconsin	1,404	1,142	1,304	1,300	1,234	1,344	1,642	1,277	129%	(365)	122%	(298)
Nine States	25,257	24,063	28,305	28,972	28,109	31,714	27,764	26,941	103%	(823)	88%	3,950
Total USA	56,678	59,145	65,945	66,811	64,592	70,193	66,295	62,634	106%	(3,661)	94%	3,898
% of USA	45%	41%	43%	43%	44%	45%	42%	43%		22%		101%
USDA-NASS, Crop Values 1993 Summary, 1994. USDA-NASS Crop Values 1991 Summary, 1992 USDA-NASS Crop Values 1989 Summary, 1990.												

The value of production depends on output and prices, and price increases due to output decreases are what caused income deviations to be smaller than production deviations. Whereas production outcomes tend to vary sharply from region to region, price effects are spread more widely through the nationwide market.

Figure 9.2 shows the distribution by county of 1993 corn production relative to the 1992 corn production. The 1992 crop set a record for corn production in much of the region. After the bumper 1992 crop, ASCS set-aside acreage requirements were raised from 5 percent to 10 percent. Thus, a crude estimate expected corn production with normal weather would be about 7.2 billion bushels or 75 percent of the 1992 production. Actual U.S. corn production in 1993 declined 33 percent nationwide, 39 percent in the nine state region, and over 50 percent in Minnesota and Iowa. The figure shows counties with higher production than the 1992 crop, with a normal production between 75 and 100 percent, with production between 60 and 75 percent, with production between 45 and 60 percent, with production between 25 and 45 percent, and with less than 25 percent of production. Counties with yields greater than 60 percent of 1992 yields receive little USDA payments; those with less than 60 percent of 1992 yields had major USDA payments.

Figure 9.2 also shows four areas where counties lost over 75 percent of their 1993 production . The northern-most counties of North Dakota and Minnesota experienced a cool growing season and an early frost. The area of far eastern South Dakota, southeast Minnesota, and northern Iowa with a large percentage of potholes (figure 4.8) experienced extensive ponding; the artificial drainage systems in this area were overwhelmed by high rainfall. This area had the highest total corn production loss. The third area consisted of a few hilly counties in southern Iowa where corn production occurs mainly in the floodplains of tributary rivers. Flood waters on this acreage destroyed these crops. The fourth area of total county crop loss was along the Missouri River in Missouri. Generally, the majority of corn production loss occurred in the pothole region. The 1992 and 1993 county level production data obtained from the National Agricultural Statistics Service (NASS) have been included in the SAST database.

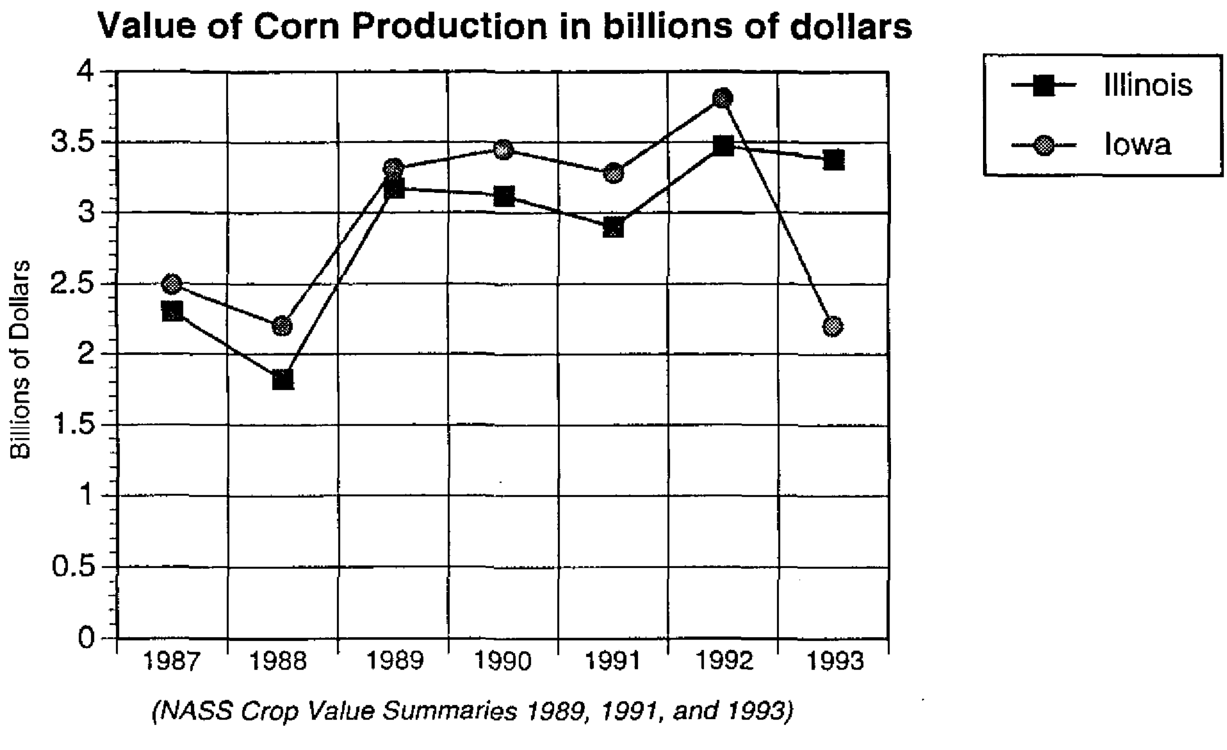


1993 Corn Production / 1992 Corn Production
< 25
60 - 75
25 - 45
75 - 100
45 - 60
>= 100
Statistics by county. Source: NASS county production data
Base from U.S. Geological Survey digital data
Albers equal-area projection, standard parallels 29 30 00
and 45 30 00, central meridian -96 00 00
50 0 50 100 150 MILES

Of course, many individual farmers suffered a great deal of damage. However, others suffered relatively minor damage and were largely compensated by higher prices, while still others (eg., upland farmers in some counties in the central parts of Kansas, Nebraska, and the Dakotas) were able to grow bumper corps because of high rainfall and thus had higher income than usual.

Most corn farmers participate in the government program and receive a deficiency payment based on the difference between the average market price and the target price multiplied by their base yield (not current yield). The increase in 1993/94 market prices is estimated to cause a decrease of $2.6 billion in Federal deficiency payments (Cassidy and Althaus, 1994). Farmers with crop losses received $1.6 billion in crop disaster assistance and $1 billion in Federal crop insurance.

Figure 9.3 Value of corn production in billions of dollars.



Additional agricultural data, such as those contained in the U.S. Census of Agriculture, would be useful when combined with physiographic provinces, soil types, and other factors to determine the relationships among regional physical characteristics and agricultural productivity.

Recommendation 9.1: Agricultural and other economics data should be included as part of the clearinghouse to ensure their availability to people conducting analysis and management in the river basin. These data should be maintained by the appropriate producing agencies.

A number of special studies are being conducted by the USACE and the SCS. The USACE is conducting a two-year floodplain management assessment mandated by Congress (HR 2445) with studies that concentrate on the upper Mississippi, lower Missouri, and tributary rivers. The SCS is in the second year of a three-year project to estimate updated average annual flood damages by river basin for the entire country. The SCS is also in the first year of a three-year project to update economic costs and benefits estimates for each PL 83-566 watershed project. These studies will provide useful data and information for analysts, policy makers, and managers.

Recommendation 9.2: The data, information and analysis resulting from the USACE floodplain management assessment studies and the SCS studies to determine average annual flood damages and costs and benefits of the PL 83-566 projects should be incorporated into the clearinghouse for the Upper Mississippi River Basin.

SELECTED ECONOMIC ANALYSES

While many economic analyses could be suggested, the economic analyses discussed here are specifically related to the provision of information concerning floodplain land use. Information from these analyses can be used to evaluate land values in relation to structural and nonstructural flood control practices and the reduction of risk with respect to flooding.

Value of land under current and alternative land uses

Policy makers are interested in the optimal use of floodplain land under various economic and policy circumstances. In order to determine optrimal land use, economist need information about the value of land in alternative uses (e.g., corn production or wildlife habitat) and under alternative circumstances (e.g., with or without levees). The following are four general cases of interest (K. Wiebe, USDA-ERS, written commun., 1994).

1) The value of land in current use under current circumstances: Estimates can be based on data from surveys of realtors, agricultural lenders, county officials, and others involved in land markets. Data on assessments or transactions involving specific parcels can be found in county tax offices or in state records offices. ASCS and ERS collect data on county-average and state-average land values from various surveys.

2) *The value of land in alternative uses under current circumstances: Estimates must* be based on analysis of costs and returns associated with alternative land uses. If the assumption is that markets are operating well within the current economic policy and environment, alternative uses may be less profitable than the land's current use, depending on additional complicating factors as noted below.

3) The value of land in its current use under alternative circumstances: Estimates must be based on analysis of how costs and returns would be affected by a change in circumstances. For example, if a breached levee is not repaired and the field it once protected is expected to flood one year in ten, the land's value in its current use may fall as a result of revenue lost to uncompensated flood damage or to flood insurance premiums. In addition, the farmer may incur restoration costs following each flood, depending on the nature and duration of each inundation.

4) The value of land in alternative uses under alternative circumstances: Estimates must be based on how input and output levels (and thus costs and returns) would be affected by the change in circumstances. For example, the farmer might consider switching to more flood-tolerant crops or restoring cropland to wetlands and seeking revenue from grazing or recreational fees.

An important complicating factor in considering the value of land in alternative uses regardless of circumstances is that the alternative uses may have social benefits such as recreation, water quality, erosion reduction, and floodwater retention that are not reflected in the returns received by private landowners. These benefits suggest a role for government in supplementing landowners' returns in order to encourage socially desirable land uses, but the benefits are extremely difficult to value (Wiebe, written commun., 1994).

Application of these four general cases to cropland affected by the 1993 Midwestern floods requires a considerable variety of data. ERS can estimate the agricultural use value of cropland under pre-flood conditions, using soils data to estimate potential yields, and farm cost survey data to estimate production costs. However, current conditions in the Upper Mississippi

River Basin include flood damage to cropland and an increased likelihood of future flooding, until or unless levees are repaired. Thus, estimation of current and post-restoration cropland values requires data on restoration costs., on the expected frequency of future flooding, and on the expected availability of disaster assistance and other factors. Comparison of these different land value estimates would allow estimation of the value of alternative partial interests in land, such as easements, that could be used as policy tools in influencing the use floodplain land in a way that balances public and private objectives.

Production costs and returns for other land uses such as pasture and forests are more difficult to estimate. Those for wetlands and other habitat are more difficult yet. However, costs and returns for these land uses must be estimated if detailed economic considerations are to be incorporated into the decision making process.

Recommendation 9.3: The Economic Research Service of USDA, FEMA, USACE, other Federal agencies, and states should cooperate to acquire data at sufficiently fine resolution to conduct economic analyses to determine the economic viability of various structural and nonstructural alternatives for controlling or reducing the effect of flooding. These data should be maintained as part of the clearinghouse.

Risk and Analysis

Recently, the USGS has developed a new methodology to evaluate risk and socioeconomic impacts associated with natural and human-induced hazards. A summary of the principles and basic concepts of the approach are given in a benefit-cost study of the value-in-use of geologic maps (Bernknopf and other, 1992). This methodology incorporates earth science information into a decision framework for evaluating alternative policies to minimize risk regionally. For example, a recently-completed study (Bernknopf and Soller, 1994) examines how different forms of mitigation can minimize costs from earthquake-triggered landslides. First, relevant data were converted to GIS format and interpreted to produce derivative map information (e.g., the shear strength of near-surface materials). The probability of earthquake-induced slope failure and the resulting property losses were estimated for individual land parcels. The conditional probability of slope failure was calculated from Bayesian statistical method, using pre-and post-earthquake data. These losses were then compared to actual losses, and the cost-effectiveness of hazard insurance and structural modifications were examined.

Managers can sue this general methodology to evaluate the cost-effectiveness of flood prevention, mitigation, and insurance. Specifically, the method could be applied to conduct regional risk assessments in areas subject to flooding. In this approach, earth-science information is used to identify potential flood-related hazards including containment structure (levee) failures.

Recommendation 9.4: **The USGS in cooperation with USDA, USACE, DOC, and FEMA should develop and implement a sicentifically based statistical method that can be used as an input to risk assessments and cost effectiveness analyses.**

Section V

CONCLUSION

The previous sections of this report have examined selected aspects of the natural system and the engineered system in the Upper Mississippi River Basin. Those discussions clearly indicate that the system is complex and its various aspects are interrelated. It should also be clear that actions on one part of the system can affect other parts of the system to a greater or lesser degree. Therefore, the system must be regarded holistically. The earlier chapters examined only those elements of the system that were necessary to aid the full committee in conducting analysis for their report. However, it is evident that considerable work remains to be done to manage the river basin as an integrated system, rather than as a collection of separate projects.

In Part V, a conceptual model of the river basin is presented as a point of departure for further analysis and as a conceptual framework for conducting integrated river basin management. In addition, a strategy for providing the scientific support necessary for management of the river basin is suggested.

Chapter 10

CONCEPTUAL RIVER BASIN MODEL

INTRODUCTION

The components of a system interact in a regular interdependent manner (Hall and Dracup, 1970). The input/output model generalizes the system behavior. Such models have been used in many applications in the most basic form or including feedback loops in water resources (Hall and Dracup, 1970) and information processing (Mills and others, 1986). Very sophisticated input/output models have been used with many forcing functions and feedbacks in analyzing the Earth system (Cubasch and Cess, 1990). This chapter discusses a conceptual model for the Upper Mississippi River Basin. The model provides a framework for a systematic approach to monitoring, assessing, analyzing, and managing the river basin.

INPUT/OUTPUT MODEL

The most basic form of a system model is an input/output model. In this model, inputs to a process are presented, the process takes place, and outputs are the result (figure 10.1).

Figure 10.1. Basic Input/Output Model

Any system has an initial condition which provides the initial inputs to processes operating within the system. The outputs from those processes have an impact on portions of the system which feedback to alter the condition of the system. In some cases, the condition of the system is also altered by external forces. This simple general model is diagrammed as figure 10.2.

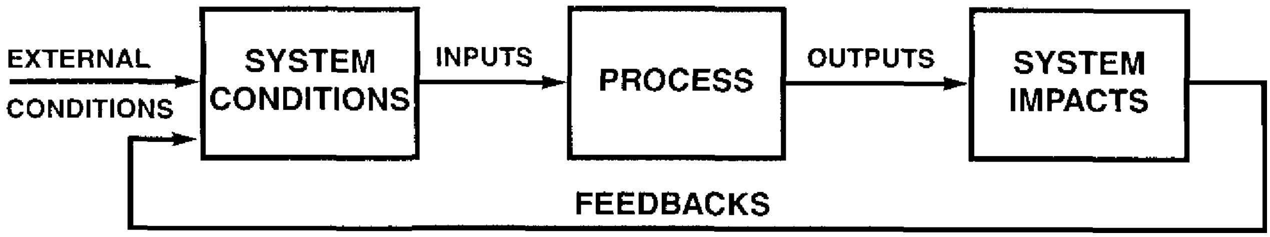


Figure 10.2. Simple General Feedback Model

RIVER BASIN SYSTEM MODEL

The simple general model is specialized to the type of system under study, i.e., a river basin system. The model is useful for evaluating forcing functions and feedbacks when viewing the river basin as a system. It is clear from the previous analysis that the river basin processes respond to natural and cultural inputs and that the ecological and social systems respond to the impacts of river basin processes. The ecological and social systems can provide feedbacks which alter the initial conditions. External processes can act as forcing functions to alter conditions as well. The model can be further refined to describe the processes in the system, in this case floods. Although that level of refinement is not necessary, it simplifies the discussion. Figure 10.3 illustrates a general river basin system model.

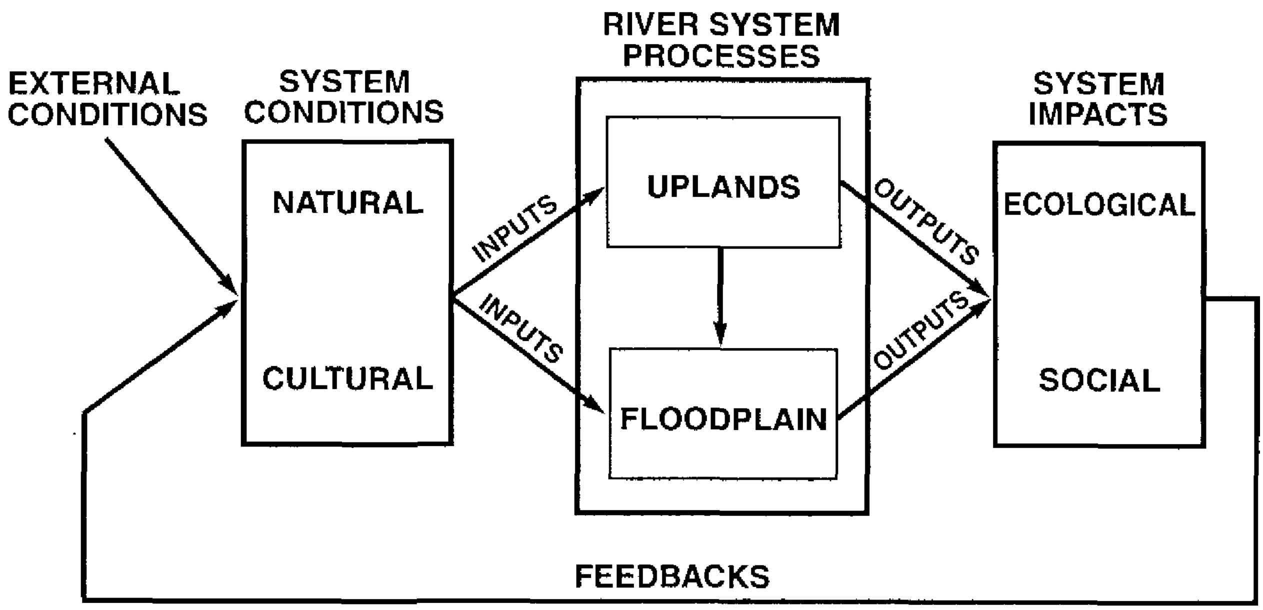


Figure 10.3. General River Basin System Model. This model is organized around flood processes.

SYSTEM CONDITIONS

System condition comprise both natural and cultural variables. Depending on the system and the condition, there can be complete interaction among the conditions, some may interact with others, and some may be static. The system conditions and the inputs that they affect are discussed here in terms of influences on flooding.

Natural Conditions

The natural conditions are atmospheric, physical-terrestrial, and biological. Of these, atmospheric conditions are predominantly externally driven on human time scales. Physical-terrestrial and biological conditions are both internally and externally driven but are primarily internal to the system. Examples of the natural conditions include weather, topography, soils, and vegetal land cover. Among the many inputs provided by these conditions are water, slope (which influences flow rate and direction), infiltration and water holding capacity of the soil, flow resistance and evapotranspiration caused by the vegetal land cover.

Cultural Conditions

The cultural conditions are engineered, regulated, or socio-economically driven. They include channelization, water impoundments, land treatments, and land use among many others. Like natural conditions, these can be either internal, or external, or a combination. They also can interact with each other. Among the many inputs provided by the cultural conditions are alterations to the flow rate, increases in surface water storage capacity, controls on flow and sedimentation rates, flow routing, and peak discharge and timing.

SYSTEM PROCESSES

System processes that relate to the organizing theme (floods) are examined and the relationships among them identified. In this case, the processes can be partitioned spatially as upland processes and floodplain processes. Both are influenced by system conditions. Upland processes affect floodplain processes but, for the most part, floodplain processes do not affect upland processes. Both have system impacts.

Upland Processes

Precipitation falling on the uplands can, depending on the system conditions, stay in place (surface water ponding capacity, snow), infiltrate (soil), evaporate (temperature, relative humidity), transpire (vegetal land cover), or run off (slope, drainage network, land cover). Most of these possible outcomes are likely to take place at varying degrees for a given precipitation event depending on the intensity and duration of the event. There are various outputs from this process; the most obvious is water and its impacts on the landscape. There can be water retention in the soil of the uplands which is necessary for plant growth, including agriculture, runoff which can cause erosion and have a negative impact on agriculture, and, for large precipitation events, heavy runoff which causes flooding either in the uplands or on the floodplain.

Floodplain Processes

Precipitation that falls on the floodplain is generally too little to cause flooding. Runoff from the uplands is the primary cause of flooding. The contribution from the upland catchment areas is in the form of quantity and timing of water. The conditions of the floodplain affect the dynamics of the flood to a greater or lesser extent depending on the magnitude of the precipitation event. The process of flood flow has a number of controlling factors. These include water inflow (quantity and duration), channel geometry (which affects conveyance), and overbank geometry (including levee placement, floodplain geometry, and land cover). Outputs from one portion of the flood pulse on the floodplain can alter the flood pulse on an adjacent portion of the floodplain. Outputs from this process include flood pulse characteristics such as stage, duration, quantity; energy distribution across the floodplain, and sediment load. These outputs have impacts on the ecological and social systems.

SYSTEM IMPACTS

Outputs from both the upland and floodplain processes can have impacts on various portions of the ecological and social systems. The ecological and social systems are tightly coupled and often respond interactively to changes.

Ecological System

The ecological system is highly dependent on the physical environment as has been discussed in previous chapters. Not only is dynamic equilibrium important for floodplain wetland ecosystems but for other ecosystems as well; however, the dynamism in the uplands is at a somewhat slower pace. On the floodplain, natural ecosystems generally respond positively to periodic flood events with increased fish spawning and nursery areas, distribution of nutrients, and establishment and maintenance of flora. Much of this response is due to natural modification of channelway and floodplain geomorphology. After the initial shock of dislocation caused by inundation, increased primary productivity results in improved forage for native terrestrial animals on the floodplain.

Social System

Conversely, the flood pulse can have a negative impact on the social system. Sometimes that impact is great as it was with the flood of 1993. The impacts include loss of life, property, livelihood, or home; reduction of agricultural productivity; physical dislocation; loss of cultural heritage; degraded living conditions, among others. All of these disruptions can be related to the event and previous responses to the event.

FEEDBACKS

The ecological response to flooding is to increase overall productivity after the initial shock of dislocation. The social response to such disruptions to the fabric of the community (agricultural, commercial, industrial, and personal) is to reduce the perceived risk from a future event. This attempt to reduce risk can take many forms, such as constructing dams to reduce the amount of water that flows into the channel and from tributaries, constructing levees to protect portions of the floodplain, moving out of harm's way, and using insurance to defray the loss in future events.

Feedbacks alter system conditions. For instance, changes in floodplain geomorphology can include relocation of channels so subsequent events will have a somewhat different impact on the system than previously; however, because of dynamic equilibrium, the changes tend to balance themselves. A natural response to the altered channelway could be increased fish productivity. A cultural response to increased productivity could be increased commercial fishing.

Social feedbacks also alter the system and can maintain or not maintain a state of dynamic equilibrium. For instance, dynamic equilibrium can be maintained by leaving the floodplain in an unaltered state. However, since the floodplain provides a highly productive environment for agriculture, this is not likely. An alternative would be to establish a constrained dynamic equilibrium: that is, constrain the dynamic equilibrium to selected portions of the floodplain and manage the boundaries. Each alternative selected has a different effect on the conditions of the floodplain. These, in turn, provide different inputs to the river basin system which alters the process and the outputs. Thus, it is important to understand the conditions, processes, and impacts of the system. This conceptual model, though described in significantly abbreviated form, clearly shows the connectivity of the various components of the river basin system with respect to flooding.

IMPLICATIONS

There are a number of implications of this conceptual model. Describing the implications can help guide responses to impacts caused by the conditions and processes involved in the system. Some of the implications of this conceptual model are listed below.

- There is considerable interconnectivity in the system. Management decisions that are made for one purpose can have major effects on parts of the system for which they were not intended.

- Activities that take place in one location on the system can have effects on another location of the system.

- When making decisions that could affect the system, one must examine potential responses of more than the sector or location that is of primary interest.

- The system should be monitored to determine if actions taken on the system (1) have the desired effect, (2) have an effect (desirable or undesirable), on another part of the system, (3) have no effect at all. This monitoring would improve decision making in the future.

- A model, or several models, of greater detail should be constructed to help identify the interconnections among the variables in the system. These models could take a variety of views: for instance, hydrologic, hydraulic, ecologic, economic, and sociologic.

- The Upper Mississippi River Basin system has a complex natural and cultural dynamic. If forecasting the impacts of various actions on the system is the goal, there must be considerable cooperation and coordination among a variety of scientific and technical disciplines to improve understanding. This cooperation and coordination should include interdisciplinary analysis and research.

While this description of a conceptual model for the river basin does not exhaustively address the complexity of the system, it serves to illustrate that complexity. It also provides an organizing framework for further analysis.

Recommendation 10.1: The Upper Mississippi River Basin must be managed as an integrated system.

Chapter 11

STRATEGY

History shows that system-wide floods, like the flood of 1993, will recur. Smaller floods, causing less system-wide damage but still seriously impacting more localized areas, will occur on a more frequent basis. Flood events are natural and necessary for a healthy functioning ecosystem, but they can be devastating for human activities that take place in harm's way. Clearly, managing the Upper Mississippi River Basin system requires managing for both natural and human needs.

Decisions will continue to be made on managing both the river basin system and its individual components. These decisions will be most effective if they are based on sound information not only of the current status of the system, but also on sound estimates of how the system will respond to decisions that are made. An effective decision support system must contain baseline information and a sound understanding of the processes taking place in the system. Analysis and research improve that understanding. Conceptual and mathematical modeling will help predict the impact of various decisions. Of course, the system must be monitored to determine if the desired results of the various decisions are actually taking place.

The strategy presented here provides a method to ensure that the natural science information necessary to contribute to sound decisions for a sustainable economic and ecologic system in the Upper Mississippi River Basin is available.

This preliminary report provides scientific background information on a number of topics in varying degrees of detail. This information is important to the deliberations of the full committee in preparing its action agenda. Preceding chapters of the report include a number of recommendations based on the scientific disciplines or topics discussed within each chapter. This chapter provides a series of overarching recommendations that form a strategy for the use of science and technology in support of managing the Upper Mississippi River Basin. The strategy is designed to dovetail with existing agency programs with some augmentation to ensure the use of the best science and technology available and to ensure a close coordination and cooperation among the Federal, state, tribal, and local governments, and nongovernment organizations.

The basic components are mapping (including digital and analog data and information representation), monitoring, analysis, modeling, data and information management and distribution, and coordination and cooperation. The details of the recommendations are in the text following the recommendations and in the recommendations listed throughout the body of the report.

MAPPING

Recommendation 11.1: Produce a baseline data set for the Upper Mississippi River Basin.

A large part of this effort has already taken place within Federal agency and state programs, and within some nongovernment organizations. The SAST has acquired a large amount of existing geographic data for the Upper Mississippi River Basin as hard copy or digital maps. Some data themes that are necessary to make sound decisions did not exist or existed in such condition that they do not fully meet the needs for analysis. The strategy for developing the appropriate set of base line data builds on the data that have already been collected by (1) improving the quality or accuracy of existing data sets, (2) developing new data to eliminate gaps in our knowledge (ie., produce sets of digital and analog maps based on the results of new analyses or observation), (3) intensifying some data sets to produce data at the appropriate scale and resolution for detailed analyses, and (4) extending data into areas for which data have not yet been collected.

(1) Data Quality: A number of data sets were found to need improvement in quality. Improvements needed include spatial accuracy of EPA toxics data, gaps in the coverage of FEMA 1 percent and 2 percent chance of occurrence flood zones, location and attribute accuracy of mainstem levees, interpretation by USGS of land use/land cover data from mid to late 1970's aerial photography. The SAST will be conducting quality assurance studies on data acquired for the database and will identify further data quality needs.

(2) Results of new analysis and observation: Some data that did not exist previously should be collected. These data which are primarily directed at operational decision making and form the baseline for monitoring include historical data sets for change analyses; locational and historical process information for geomorphologic features that affect natural habitat, effectiveness of levees, agricultural viability, and structural integrity of floodplain infrastructure; new data sets necessary for evaluating ecological systems including species-centered and community-centered data; and socio-economic data that allow for monitoring future change in the system. In addition, cultural sites and areas of

high cultural value should be identified to ensure adequate understanding of their susceptibility to system changes.

(3) Intensification: Some data are too coarse for certain types of analysis and modeling. For instance, DEM data currently available are not of sufficient resolution for analysis of seasonal wetlands, hydraulic modeling of the floodplains, or detailed hydrologic modeling of much of the uplands; economic data are of too coarse resolution to accurately analyze impacts of the 1993 flood on the floodplains, or to analyze the comparative economic impacts of alternative activities either on floodplains or in specific locations in the uplands; and existing basinwide soils data are too coarse to analyze the effect of different activities on local environments. At a minimum, high resolution DEM's should be acquired, economic data should be intensified, and intensification and digitizing of soils data should be accelerated.

(4) Extension of data: Many of the data that have been acquired in the floodplains of the main stems of the lower Missouri, upper Mississippi, and Illinois Rivers should be extended into the major tributaries. This extension is necessary for establishing the hydrologic link between the uplands and the floodplains of the main stems and to provide the scientific and data support necessary in those areas for systemwide planning and disaster response.

MONITORING

Recommendation 11.2: Establish a monitoring program to identify changes to the Upper Mississippi River Basin system. This program should link to and integrate ongoing monitoring programs for the physical, ecological, and socioeconomic sectors of the environment.

A monitoring program should be established to evaluate continually the response of the system to policies implemented and management techniques used. A number of data themes should be monitored. These include land use and land cover (USGS, EPA, NBS, other Federal agencies, states, and tribal governments should coordinate in this effort); ecological indicator species, communities, and biological processes (NBS should lead this effort and coordinate with FWS and EPA on the Federal level and with states and tribal governments); channel changes, structural and nonstructural flood control features (USACE should take the lead and primarily work with SCS, the states, and tribal governments); gaging flood flows, stage, and other characteristics (USGS should lead and work with USACE, NWS, FEMA, and states and tribal governments); location and condition of toxic materials and dynamics of toxics dispersal by hydrologic and hydraulic means (EPA lead with USGS and USDA and states cooperating); economic characteristics (USDA and DOC lead with other Federal agencies, states, tribal, and local governments cooperating as appropriate).

ANALYSIS

Recommendation 11.3: Conduct initial and ongoing scientific analysis of the Upper Mississippi River Basin system. This analysis should build and expand on the work initiated by the SAST. The analysis should be conducted by all levels of government and relevant non government organizations. The analysis should be conducted to improve understanding of how the various parts of the system interrelate and to provide new understanding to policy and management decision makers.

The SAST conducted its activities in an interdisciplinary atmosphere which led to findings and new understanding that would not have taken place if each of the disciplines had worked independently. Such interdisciplinary analysis should be instituted as the norm rather than the exception. A variety of specific analyses should be conducted to provide the basis for integrated river basin management. The analyses can be characterized broadly as (1) regionalization, (2) process studies (systemwide, uplands, and floodplains), (3) engineering and design.

(1) Regionalization: It is necessary to evaluate existing and new regionalization schemes to develop hydrologic response units (HRU's) and ecologic response units (ERU's). Both of these are necessary for modeling the systems' response to various forcing functions and feedbacks and to determine how components of the system affect other components (eg., for HRU's how activities in the uplands affect flooding on the mainstem floodplains, and for ERU's how changes in the physical system affect biological species or communities). HRU's should be developed by the USGS in cooperation with the SCS and NWS. ERU's should be developed by NBS in cooperation with other DOI and USDA agencies, EPA, and the states.

(2) Process studies: Initial analysis by the SAST revealed a number of areas in which additional study is necessary to support more informed decision making. These include the effects of land treatment on hydrologic and ecologic response in the uplands and floodplains (USDA agencies lead in coordination with DOI agencies and NWS); the effects of fluvial processes, surficial geology, floodplain geomorphology, and topography on the performance and integrity of levees (USACE and USGS cooperate and coordinate with SCS and state and tribal governments); the effects of various land uses and covers on flood characteristics (USACE and USGS coordinate with other Federal and non-Federal organizations); the relationship between precipitation events, upland floods, floodplain floods, and low flows (NWS, USGS, and USACE coordinate); identifying the sources, sinks and transport of nutrients and toxics (DOI, EPA, and other Federal and non-Federal organizations coordinate); the diffusion of disease during flood events (NIH in coordination with other Federal, state, tribal, and nongovernment organizations) and the social impact of floods (NSF, NIH, DOC, and other Federal and non-Federal organizations).

(3) Engineering and design: Examine alternative placement of levees, retention structures, and nonstructural flood control mechanisms to determine the effects of the physical environment on their integrity (i.e., test for the effects of surficial geology, floodplain and channelway morphology, topography, relationship to existing infrastructure, relationship to historical channelway, and land covers on buffer zones, floodways, and elsewhere on floodplain). Examine alternative design of levees, retention structures, impoundment channel, control structures, and nonstructural flood control mechanisms to determine methods for adapting to the physical environment while operating in harmony with the biological and cultural environments. The USACE should lead this effort and coordinate with appropriate Federal and non-Federal organizations.

MODELING

Recommendation 11.4: Develop ecologic and hydrologic models of the river basin and advanced hydraulic models of the floodways of the main stems and major tributaries.

Three types of models should be expanded or developed for the river basin: (1) hydrologic, which examines the hydrologic cycle in the basin; (2) hydraulic, which examines the flood flow characteristics on the floodplains; and (3) ecological, which examines the interrelations among various biological species and communities and the way they interact with the physical, chemical, and cultural environment.

(1) Hydrologic models covering small areas have been developed, but no systemwide hydrologic model has been developed. Such a model would be useful to describe the impacts of various activities on the overall system. USGS should lead this effort in coordination with NWS, USACE, and agencies of USDA. State governments should also cooperate in this effort.

(2) Initially, one-dimensional hydraulic models with imbedded two-dimensional models in critical areas should be developed for the mainstem Missouri, Mississippi, and Illinois Rivers. For the longer term, the two-dimensional models should be expanded to cover entire floodplains. Such hydraulic models should also be developed for major tributaries. This effort should be led by USACE with the cooperation of USGS, NWS, and the states.

(3) Ecological models of the system should be developed by the DOI in cooperation with USDA, EPA, NSF, states, tribal governments and NGOs. These models should a) define the basic structural and functional attributes of plant and animal communities and the linkages among the watershed, floodplain, and river channel; b) define responses of those communities to changes in the physical, chemical, and cultural environments, and; c) define the services that a functional river-floodplain ecosystem provides society, and d) provide predictive scenarios of community responses to a range of management strategies and causal relationships that can help forecast declines and improvements in watershed river-floodplain ecological integrity.

These models should be integrated and link such technologies as remote sensing, geographic information systems, time-series analysis, and visualization, as appropriate to ensure the rapid ingest and processing of data and the effective presentation of information.

DATA MANAGEMENT AND DISTRIBUTION

Recommendation 11.5a: Appropriate agencies should manage and maintain the data that are under their purview to standards and specifications that allow intercomparability and interchangeability.

Currently much of the data are produced by agencies for specific purposes and are not necessarily designed to support a broad range of users and applications. Typically, applications for which the data are not specifically designed are not considered when the data are made available; consequently, valuable information may not be available to the user. To alleviate this problem, the FGDC metadata standard should be met and data should be maintained in commonly accepted exchange formats. In addition, specific uses may require a level of data compatibility that is greater than extensive exchange formats or structures allow. In those cases, to make the data compatible with the SAST database, additional effort must be made to ensure data compatibility so that the data can be used in time of emergency. Agencies maintaining their data should work with the central nodes to make sure that the data have the appropriate level of compatibility. For flood analysis and response, USGS should coordinate with FEMA and USACE to ensure that appropriate standards and structures are established. Individual agencies have the responsibility of meeting those standards.

Recommendation 11.5b: Establish a distributed clearinghouse for data and information. This clearinghouse should be part of the National Information Infrastructure and meet the specifications of the Federal Geographic Data Committee.

The data and information that have been acquired by the SAST and that will be identified and incorporated into the database in the future should be made available to the widest possible user community. Availability can be accomplished by using a data clearinghouse. The SAST clearinghouse operates on a distributed model with EDC acting as the central node and other organizations acting as nodes on the system. Each node has responsibilities for maintaining and distributing data to the user community. The central node maintains and distributes those data which are directly relevant to the mission responsibility of the agency maintaining that node. It also stores and distributes data which has been acquired and for which no mission requirement exists within any organization. These "orphan" data sets are not maintained, merely stored and distributed. Other nodes maintain and distribute their own mission-related data. The central node also assists other organizations in designing mechanisms to meet quality assurance, documentation, data intercomparability, and distribution requirements. The clearinghouse should also include states, tribal governments, and nongovernment organizations.

The distribution system maintains data on-, near-, and off-line. Data maintained online are those whose ready access is important to users in times of emergency or that it are technologically advantageous to distribute through online means. For large data sets that would be too cumbersome to distribute by on-line means, near-line access is maintained. For data sets of large volume and for which there is little demand, offline storage is appropriate.

Details of the clearinghouse activity will be described in the database report. However, it is necessary that support be given to this activity at the highest levels of government to ensure the data and information are made available to all levels of government and to nongovernment organizations.

SCIENTIFIC COORDINATION

Recommendation 11.6: Establish a coordinating body of scientists to review programs of scientific research and data collection various levels of government and advise Federal, state, tribal, and local governments and nongovernment organizations on the scientific activities that are and should be conducted to support the management of the Upper Mississippi River Basin. This interdisciplinary body of scientists would serve as principal scientific advisors to the River Basin Commissions and the Water Resources Council. Additional interdisciplinary scientific bodies should be established to meet specific goals of management and disaster response in the Upper Mississippi River Basin.

The interdisciplinary bodies of scientists should be established at various levels and can work within existing organizational structures. They are the (1) advisory group, (2) the analysis group, and (3) the disaster response group.

> (1) The Advisory Group: This group should be established to provide scientific advice to the Water Resources Council and the Mississippi River Basin Commission. It should be composed of scientists from various disciplines and Federal and non Federal government agencies and the nongovernment community. The initial activity of this group should be to conduct an evaluation and budget crosscut of the scientific and data gathering activities that are taking place to identify gaps and overlaps. At the Federal level, this crosscut should be conducted under the auspices of OMB and OSTP. Federal agencies represented on this group should include at a minimum NSF, DOI (FWS, NBS, USGS), USDA (ARS, ERS, SCS), USACE, DOC (Census, NWS), FEMA, and EPA. Membership from these agencies should include senior scientists and engineers who have a sound understanding of the specific scientific issues involved

and the agency's programs. To inform the decision making process, this group should provide advice to policy level bodies on the data that must be gathered, the analysis that must be accomplished, and the status of changes in the science and the environment. This group would work part time, convening to conduct crosscuts and to give advice.

(2) The Analysis Group: A multidisciplinary group of scientists from various agencies and levels of government, and from nongovernment organizations should be established. The purpose of this group should be to maintain cognizance of the state of the science and data acquisition and to develop analytical and management techniques for use by scientists and managers in the river basin. Some members of this group will respond rapidly during and after flood events to gather information useful for flood prediction, design of flood control or mitigation mechanisms, or improved response to flooding. This group will also support the integration of data acquisition and distribution. Governmental and nongovernmental organizations would detail scientists to this working level group of scientists who would maintain close ties with the Federal Geographic Data Coordinating Committee, the National Advanced Remote Sensing Applications Program, and other interdisciplinary, interagency, coordinating and research activities. At the Federal level, a program to house such a group of researchers and analysts should be established in the USGS in cooperation with USACE, NOAA, NBS, FWS, EPA, FEMA, and other agencies as appropriate.

(3) The Disaster-Response Group: In times of emergency it is important to have the appropriate tools and information as well as the skilled people readily available to use them. A subset of the Analysis Group should be devoted to disaster response. This group should be coordinated by FEMA and contain at a minimum USACE, EPA, and USGS. The team should conduct disaster planning and response drills using available systems. The team should also develop techniques and advise in hardware and software system development.

SCIENTIFIC ANALYSIS AND SYSTEM MANAGEMENT

The SAST recognizes that some of the activities recommended here are either planned or being executed by organizations within or outside the Federal government, hence the recommendation to conduct a budget crosscut in order to minimize duplication of expenditures.

In addition, the SAST recognizes that many of the recommended activities have applicability beyond the boundaries of the Upper Mississippi River Basin. Those activities should be conducted in such a way that they will ensure the broadest application possible. For instance, the establishment of a data and information clearinghouse is important to the management of the upper Mississippi River basin, but the clearinghouse, if well coordinated with the FGDC, can act as a model for topically based clearing houses and a national data and information clearinghouse effort.

The SAST has concentrated its efforts on a particular topic, floods, in a particular region, the Upper Mississippi River Basin, and thus, has selected variables for inclusion in the database and for analysis that are relevant to that topic. Certainly, some of those variables can be relevant to many other topics as well, but those topics would include additional variables not contained in this database. Topically relevant variables readily available through a clearinghouse can be useful for both planning for and responding to disasters and other social and environmental problems. Data and information used in planning for disaster mitigation and adaptation are also valuable for disaster response. Disasters planned for are more easily responded to. The activities of the SAST were conducted in a short time frame in response to a disaster. Planning ahead and coordinating across Federal agencies and through the various levels of government and nongovernment organizations should help reduce the impacts of disasters on the Nation.

APPENDICES

APPENDIX A

PRODUCTS GENERATED BY SAST

SOME PRODUCTS AND ANALYSES PROVIDED TO THE INTERAGENCY FLOODPLAIN MANAGEMENT REVIEW COMMITTEE BY THE SAST

- Built draft digital database with many different coverages for the Upper Mississippi River Basin. Currently approximately 250 GigaBytes.
- Delivered 140+ draft maps, overlays and analyses to the Interagency Floodplain Management Review Committee (FMRC) including
  - 100K scale maps and overlays showing:
    - Base data (17 overlays)
    - Levees (17 maps)
    - Flood Extent (17 overlays)
    - Flood Probability (100- and 500-year floodplains) (17 overlays)
    - Fish Spawning areas and Mussel Beds (10 overlays)
    - Wildlife and Bird Habitat (11 overlays)
  - Regional scale maps for various themes
    - Basin extent and hydrography
    - Terrain units
    - Shaded topographic relief
    - Hydric soils
    - Surface water ponding
    - Available water storage capacity
    - FSA - FACTA runoff reduction
    - CRP runoff reduction
    - Soil orders
    - Soil slopes
- One SAST member was co-located with the IFMRC in Washington, D. C. to generate one-off maps and statistical analyses on an as needed basis from March through June.

SPECIAL LOCAL MAPS

- Pre, During, Post Flood enhanced Thematic Mapper Images for Missouri floodplain on Moberly 1:100,000 - scale quadrangle
- Pre, Post Flood enhanced Thematic Mapper Images of the St. Louis 1:100,000 - scale quadrangle
- Draft map of focused energy on the floodplain of the Moberly 1:100,000 - scale quadrangle
- Floodplain energy level delineations for the Moberly 1:100,000 - scale quadrangle
- Marshall, Missouri 1:100,000 - scale quadrangle 1879 landcover.

ADDITIONAL MAP PRODUCTS

- Slope Map of the Upper Mississippi River Basin area
- Slope Aspect Map (Flow Direction Map) of the Upper Mississippi River Basin area
- Slope Variance Map of the Upper Mississippi River Basin area
- Upper Mississippi and Missouri River Basins: Major Land Resource areas: Overlay
- Present Channel and Levees with Historical Channel and Land Use
- Change in Land Cover/Land Use, Pool 26, Upper Mississippi River, 1891 - 1989
- Change in Land Cover/Land Use, Open River, Upper Mississippi River, 1891 - 1989
- Natural Heritage Inventory: Upper Mississippi River System Distribution
- Missouri River Significant Biological Habitat: Land Cover with 1991 Channel
- Mississippi River Significant Biological Habitat
- 1993 FCIC Crop Insurance Payments
- 1993 ASCS Crop Disaster Payments
- 1990 Population
- 1990 Median Household Income
- 1993 Corn Production/1992 Corn Production

Appendix B

WHITE HOUSE DIRECTIVE ESTABLISHING SAST

THE WHITE HOUSE

WASHINGTON

November 24, 1993

TO: G. Edward Dickey, Acting Assistant Secretary of the Army (Civil Works)
Gary Foley, Acting Assistant Administrator for Research and Development, U.S. Environmental Protection Agency
James R. Lyons, Assistant Secretary of Agriculture for Natural Resources and Environment
James Lee Witt, Director, Federal Emergency Management Agency

FROM: John H. Gibbons, Assistant to the President for Science & Technology
T.J. Glauthier, Associate Director, Office of Management and Budget
Katie McGinty, Director, White House Office of Environmental Policy

SUBJECT: *Directive on the Establishment of a Scientific Assessment and Strategy Team in Response to Flooding in the Mississippi River Basin*

The purpose of this directive is to establish an interagency Scientific Assessment and Strategy Team (SAST) responsible for providing scientific advice and assistance to officials responsible for making decisions with respect to flood recovery in the upper Mississippi River basin. The team will develop and provide information to support the decision-making process regarding both nonstructural and structural approaches to flood control.

A key responsibility of the SAST will be to organize the information in existing databases to aid in the near-term and long-term decision-making process. Specifically, the team shall identify broad areas of the major floodplains of the upper Mississippi River and the lower Missouri River that, from a scientific perspective, are most suitable for alternative flood control approaches including wetland restoration. We anticipate that this information will be helpful to states and communities, as well as federal agencies, in making decisions with respect to flood recovery and the longer-term protection and cost-effective use of resources in the Mississippi River basin.

This effort will be coordinated by Mark Schaefer of the White House Office of Science and Technology Policy (OSTP) and Mollie Beattie of the Department of the Interior with the Assistance of Michele Altemus. The team will carry out its activites at the U.S. Geological Survey's Earth Resources Observing System (EROS) Data Center (EDC) in Sioux Falls, South Dakota, and will be directed by John Kelmelis of the USGS.

The SAST will be comprised of scientists and engineers with a broad range of expertise related to river basin management, flood control, and ecosystem management. At a minimum, the following departments and agencies will be represented on the team: Department of Agriculture, Army Corps of Engineers, Federal Emergency Management Agency, Department of the Interior, and the Environmental Protection Agency. Each of these agencies shall nominate individuals to serve on the SAST for a period of approximately eight weeks. Nominees must have a strong scientific background and be familiar with geographic information systems. The required skill mix for the team is attached. Please fax the nominations to Mark Schaefer of the Office of Science and Technology Policy no later than Friday, December 3 (telephone: 202-456-6202; fax: 202-395-1571).

Resources to support this effort will be provided through existing agency budgets supplemented by funds dedicated to flood recovery.

APPENDIX C

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REVIEWERS

Over 130 copies of the draft report were distributed for review. Many of the people who were contributors to the preliminary report also reviewed parts of the document. Names of those people are not included in this list nor are members of the full FMRC who reviewed this document as well. The SAST is thankful for the thoughtful comments of the reviewers and considered all comments in preparing the report for publication. However, the SAST accepts sole responsibility for the information contained in this report. Reviewers included:

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The SAST is also thankful for the wise council and advice provided at the initiaition of the project by **Dr. Gilbert White**, Natural Hazards Institute, Boulder, CO.

APPENDIX D

DATABASE NOMENCLATURE

Partial description of standard nomenclature for SAST databases. This table contains excerpts from an online documentation file, and may not conform to traditional standards for presentation of tabular data.

DEFINITION OF UPPER MISSISSIPPI RIVER BASIN

For purposes of this project, this entire Upper Mississippi River Basin is called the 'full basin'. The coverage corresponding to this area is called 'basin_bound'.

DEFINITION OF FLOODPLAIN STUDY AREA

For purposes of this project, this smaller study area is called the 'study area'. The coverage corresponding to this area is called 'study_bound'.

CHARACTERS USED IN NAMES

Directories	Directory names should not contain any non-alphanumeric characters, except for '_' or '-'. For consistency, it is recommended to use '_', but not '-'.
Coverages	Coverages are directories, and should be named accordingly.
Grids	Grids are directories, and should be named accordingly. When grids and coverages are stored in the same workspace, it is recommended to add the suffix '_g' to the name of the grid.
Info file names	The recommended delimiter is '.'.
Info items	The recommended delimiter is '-'. Do not use items defined as numeric (type N).
Files	The recommended delimiter is '.'.

LIBRARY NAMING CONVENTIONS

Not finalized...

COVERAGE NAMING CONVENTIONS

Area Names

Basin	The entire Upper Mississippi above Cairo, including the Missouri.
Study	The floodplain study area, the Upper Mississippi and the pertinent areas of the Missouri below Gavins Point Dam.

River Basin Names:

Il	Illinois
Mo	Missouri -- prefix for coverages specific to the Missouri River Basin.
Ms	Mississippi -- prefix for coverages specific to the Upper Mississippi River Basin, not including the Missouri.

State Names:

The two-letter abbreviation should be used:

co,il,in,io,ks,mi,mo,mn,nd,ne,mt,sd,wi,wy

Scales:	Map scale of source of a standard data layer:
24	1:24,000
100	1:100,000
250	1:250,000
2m	1:2,000,000 or 1:2,500,000

INFO ITEM NAMING CONVENTIONS

For consistency, and to ensure that databases can easily be related, the following conventions should be used.

States and Counties:

fips-code	5,5,i	5-digit state/county code
state-code	2,2,i	2-digit state code
cnty-code	3,3,i	3-digit county code
state	2,2,c	2-character state abbreviation
state-name	20,20,c	state name
cnty-name	32,32,c	county name

Hydrologic Units:

huc	8,8,i	8-digit hydrologic unit code (cataloging unit)
huc-unit	8,8,c	character version of huc, padded with zeroes

huc-2	2,2,i	2-digit hydrologic region code
huc-4	4,4,i	4-digit hydrologic subregion code
huc-6	6,6,i	6-digit hydrologic accounting unit code

Latitude/Longitude:

lat	6,6,c	latitude, in ddmmss, padded with zeroes
long	7,7,c	longitude, in dddmmss, padded with zeroes
dlat	4,9,f,5	latitude, in decimal degrees
dlong	4,9,f,5	longitude, in decimal degrees

Sampling Sites:

site-num	15,15,i	site designation number
site-name	50,50,c	site name
elev or datum	4,8,f,2	elevation of site (usually in feet)
darea	4,10,f,2	drainage area (usually square miles)
cdarea	4,10,f,2	contributing drainage area

USGS Quadrangles:

quad-code	8,8,c	standard USGS quadrangle index code, based on the southeast corner (e.g. 38096-A1)
tic-se	7,7,i	numeric equivalent of the quad-code, based on the southeast corner (e.g. 3809611)
lat-se	6,6,c	latitude of the southeast corner, in ddmmss
long-se	7,7,c	longitude of the southeast corner, in dddmmss
quad-name	40,40,c	name of quadrangle, without state abbreviation
states	14,14,c	set of 2-character state abbreviations

TIC NAMING CONVENTIONS

The following applies to all tics based on standard map quadrangle corners. Tics should be named to match the TIC-SE item in quadrangle coverages. This is a 7-digit integer. Digits 1-2 are the degrees part of the latitude. Digits 3-5 are the degrees part of the longitude. Digit 6 refers to the minutes-seconds of latitude, described below. Digit 7 refers to the minutes-seconds of longitude, described below.

Explanation of digits 6 and 7:

Digit	minutes	seconds	USGS index	
-----	-------	-------	lat	long
1	00	00	A	1
2	07	30	B	2
3	15	00	C	3
4	22	30	D	4
5	30	00	E	5
6	37	30	F	6
7	45	00	G	7
8	52	30	H	8

For example, the point 38-37-30, 98-15-00 would have a TIC-ID of 3809863, and correspond to the southeast corner of the USGS quadrangle 38098-F3. The polygon coverages quad250, quad100, and quad24 contain appropriately numbered tics at each quad corner. The program pullquad.aml may be used to select subsetsof these quadrangle coverages.

APPENDIX E

DATABASE MASTER DIRECTORY

Master directory structure of the database on the SAST network as of July 1, 1994. The database and its structure is in development and will be finalized by September 1994.

DIRECTORY STRUCTURE

/MISSGIS top-level directory for all GIS data

/Sys standard copies of programs, lookup tables, etc.

/atool	aml programs, linked to arcexe61
/symbols	symbol sets, linked to arcexe61
/projection	standard files for map projections
/lookup	lookup tables
/proc	custom programs for processing, display, etc.
/logo	coverages or map compositions of agency logos
/sastamls	sast amls, linked to arcexe61

/Template templates of various themes

/USA

- /county boundaries 1:100,000
- /county boundaries 1:2,000,000
- /federal boundaries 1:2,000,000
- /geological boundaries 1:2,000,000
- /geomorphic region
- /huc boundaries 1:250,000
- /huc boundaries 1:2,000,000
- /lake boundaries 1:2,000,000
- /landuse boundaries 1:2,000,000
- /railroads 1:2,000,000

/reservoirs
/rivers 1:2,000,000
/rivers 1:4,000,000
/state boundaries 1:2,000,000

/Study Basin - coverages clipped to the Upper Mississippi River Basin, and Info and dbase files on county level statistics

/basin boundary
/county boundaries 1:100,000
/county boundaries 1:2,000,000
/flooded region boundary
/huc boundaries 1:250,000
/huc boundaries 1:2,000,000
/reservoirs
/rivers 1:2,000,000
/rivers 1:4,000,000
/roads 1:2,000,000
/state boundaries 1:2,000,000

/Data

/vector

/birds Mississippi River
/birds Missouri River (potential)
/climate
/digital elevation (dem) 3-arc second data
/dlg_100k lakes
/dlg_100k miscellaneous transportation
/dlg_100k railroads
/dlg_100k roads
/dlg_100k streams
/EPA Toxic Release Inventory (TRI)
/EPA Super Fund Cleanup sites
/floodextent
/floodplain

/floodprobability
/historical Mississippi River
/historical Missouri River
/landuse - Anderson Level 1 Classification
/levees
/mussels Mississippi River
/mussels Missouri River (potential)
/National Park Service historic sites
/National Wetlands Inventory
/precipitation
/rainman database
/rf3 river reach database
/river miles
/runoff contour model 1:2,00,000
/spawning Mississippi River
/spawning Missouri River (potential)
/STATSGO - soil survey grouped data
/stream gauges
/wildlife Mississippi River
/wildlife Missouri River (potential)

/raster (generic geo-registered images and ARC/GRID format will be stored for each satellite image)

/Advanced Very High Resolution Radiometer (AVHRR) data and derivative products

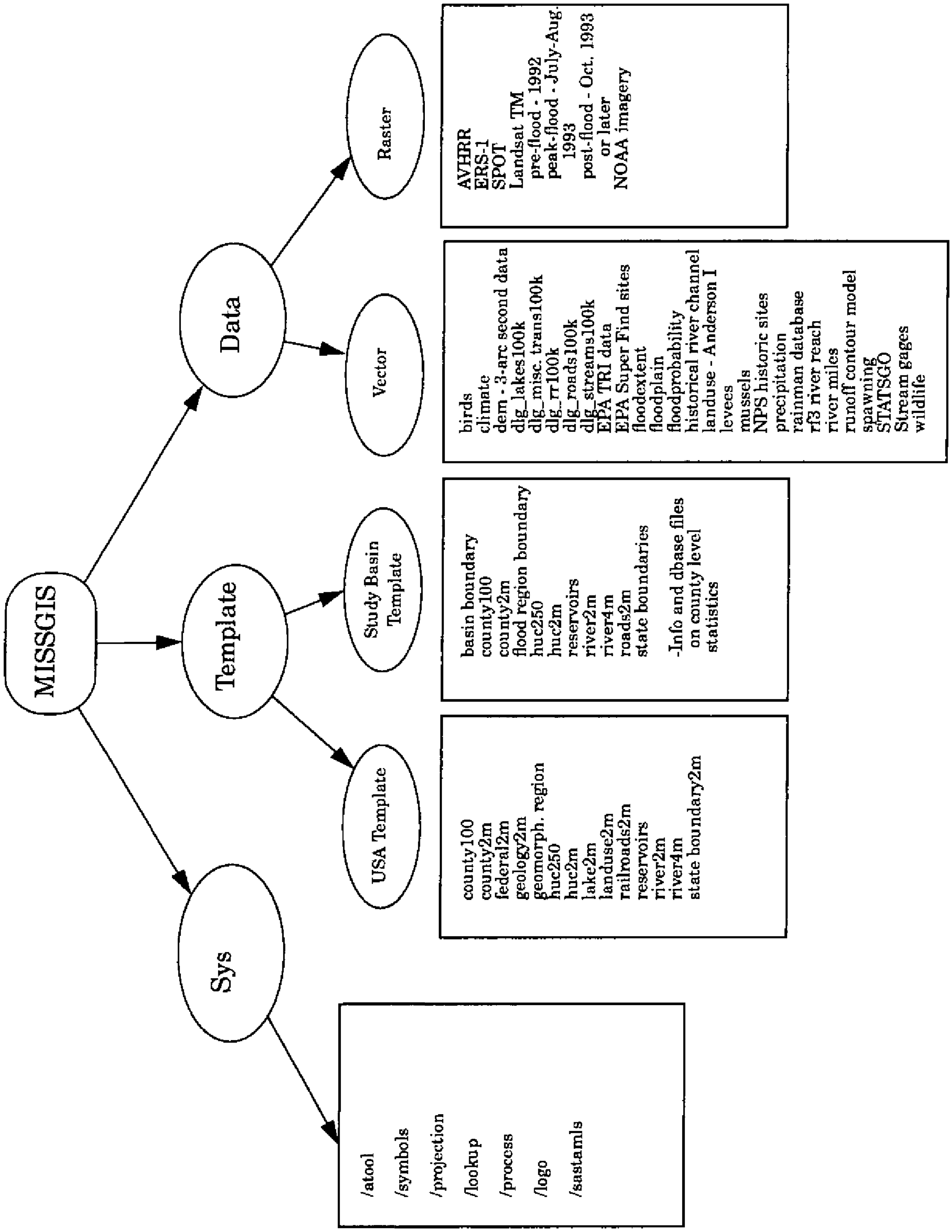
/Earth Resource Satellite (ERS-1) imagery of the Upper Mississippi River Basin

/SPOT satellite imagery of the Upper Mississippi River Basin

/Landsat Thematic Mapper imagery for:

pre-flood - 1992 or earlier
peak-flood - July-August 1993
post-flood - October 1993 or later

/National Oceanic and Atmospheric Administration NOAA imagery for the Upper Mississippi River Basin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landuse2m
railroads2m
reservoirs
river2m
river4m
state boundary2m
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reservoirs
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river4m
roads2m
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-Info and dbase files on county level statistics
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climate
dem - 3-arc second data
dlg_lakes100k
dlg_misc_trans100k
dlg_rr100k
dlg_roads100k
dlg_streams100k
EPA TRI data
EPA Super Find sites
floodextent
floodplain
floodprobability
historical river channel
landuse - Anderson I
levees
mussels
NPS historic sites
precipitation
rainman database
rf3 river reach
river miles
runoff contour model
spawning
STATSGO
Stream gages
wildlife
AVHRR
ERS-1
SPOT
Landsat TM
pre-flood - 1992
peak-flood - July-Aug. 1993
post-flood - Oct. 1993 or later
NOAA imagery

APPENDIX F

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